Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNO-ECONOMIC FEASIBILITY STUDY FOR A SMALL SCALE PORTLAND CEMENT PLANT IN NORTHERN CANADA

FINAL REPORT
by:
HARDY BBT LIMITED
EA-11352

Work on the project was conducted under the auspices of the Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources Canada.

DSS File No. 15SQ.23440-8-9008

DSS Contract Serial NO. 23440-8-9008/01-SQ

CANMET Scientific Authority: Mr. A. Lane

Date: May 12, 1989

172 pp

MICROMEDIA

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EXECUTIVE SUMMARY

A Techno Economic Feasibility study for a small scale Portland Cement Plant in Northern Canada was undertaken by Hardy BBT Limited. The study was commissioned by Supply and Services Canada. Of particular interest in the study was use of vertical kiln plants for small scale cement production. At the completion of the market study involving current uses, users, suppliers, transportation methods, pricing, current specifications, future uses, etc., it became quite apparent that a vertical kiln plant was not a suitable choice even if a cement plant was economically feasible. Inferior product quality, unavailability of used parts, difficulty of start-up and shutdown procedures, high cost of extra labour for clinker sorting and high cost of energy were some of the major issues influencing the conclusion of not considering a vertical kiln plant. As a result, the efforts were directed to consider feasibility of a small scale horizontal rotary kiln plant.

The study indicated presence of a relatively very small steady demand of 17,000 tonnes/year and peak demand of 32,000 tonnes/year within The Northwest Territories and The Yukon Territories market under consideration. This demand is satisfactorily being met by two large cement manufacturers in Alberta and British Columbia. Investigation of availability of raw materials indicated that the main ingredients, limestone and shale or clay, will be available within a reasonable distance from most major population and/or commercial centers. Since the demand was noted to be concentrated near major population centers, establishment of a cement plant near such a center with relatively easy and economical access to water and road transportation was considered most appropriate. Accordingly, two scenarios were analyzed to determine return on investment and associated cash flows.

One scenario considered a small scale plant in Norman Wells to serve the entire Northwest and Yukon Territories market of 17,000 to 32,000 tonnes of cement per year. The other scenario considered a plant in Yellowknife to serve the cement demand of 10,000 to 20,000 tonnes per year only in The Northwest Territories market. Different pricing structure was assumed in each case. The investment analysis indicated that, in each case, the payback period was too long compared to other available investment opportunities. Also, the viability of a plant in the North was considered quite vulnerable to market factors such as size, penetration and competition. The overall study indicated that a small scale cement plant in Northern Canada did not appear to be feasible or meritorious on the basis of the current technical and economic factors. Additional in-depth consideration of a few market factors such as price-volume relationships, backhaul rates by a serious investor will be required as a next step leading to investment decisions. A preliminary selection of a plant location, testing of raw materials leading to the raw feed design, specifying equipment in detail and verification of capital and operating costs are a few actions considered appropriate for an interested investor.

SOMMAIRE DE LA DIRECTION

Une étude de faisabilité économique Techno a été réalisée par Hrdy BBT Limited, pour une petite entrprise du Nord-ouest canadien, la Portland Cement Plant. L'étude a été commandée par Approvisionnement et Services Canada. Elle s'intéressait en particulier à l'utilisation d'usines à four vertical, pour la production de ciment à petite échelle. L'étude de marché concernant les utilisations courantes, les utilisateurs, les fournisseurs, les méthodes de transport, les prix, les caractéristiques courantes, les utilisations futures, etc, a démontré qu'une usine à four vertical n'était pas un bon choix, même si une telle usine de fabrication de ciment était réalisable au niveau économique. Une qualité de produit inférieure, l'indisponsibilité des pièces usagées, la difficulté des procédures de mise en marche et de mise en arrêt, le coût élevé de la main d'oeuvre supplémentaire pour le triage du mâchefer et le coût élevé de l'énergie sont quelques-uns des facteurs importants qui ont influencé la conclusion de ne pas considérer la solution offerte par les usines à four vertical. Les efforts se sont done portés sur l'étude de la faisabilité d'une usine à four horizontal rotatif, de petite échelle.

Dans les marchés sous observations, soit ceux représentés par les Territoires du Nord-ouest et le Yukon, l'étude a indiqué la présence d'une petite demand constante relative de 17 000 tonnes/année et d'une demande de pointe de 32 000 tonnes/année. Cette demande est recontrée de façon satisfaisante par deux fabricants de ciments importants en Alberta et en Colombie-Britannique. Une recherche effectuée sur la disponibilité des matériaux bruts nécessaires, la pierre calcaire ou la glaise, a démontré leur existence à une distance raisonnable des centres importants de population et/ou commerciaux. Puisque que l'on a remarqué que la demande se concentrait près des centres de population importants, il semble plus approprié d'établir une usine de fabrication de ciment près d'un tel centre, avec un accès facile et économique à l'eau et aux routes de transport. En accord avec ceci, deux scénarios ont été analysés pour déterminer les profits après investissement et la rentrée d'argent.

L'un des scénarios considérait l'établissement d'une petite usine à Norman Wells, qui servirait le marché complet de 17 000 à 32 000 tonnes de ciment par année des Territoires du Nord-ouest et du Yukon. L'autre scénario s'est penché sur la possibilité d'une usine à Yellowknife, pour servir la demande en ciment de 10 000 à 20 000 tonnes par année, pour le seul marché des Territoires du Nord-ouest. Une structure de prix différente a été assumée dans chacun des cas. L'analyse pour l'investissement a indiqué, que pour chaque cas, la période de récupération était trop longue en comparaison avec les autres opportunités d'investissement disponibles. De plus, les chances de succès d'une usine dans le Nord ont été qualifées de vulnérables, en considération des facteurs de marché tels que la taille, la pénétration et la compétition. L'étude générale a indiqué que l'établissement d'une petite usine dans le nord canadien ne semble pas être réalisable ni méritoire, selon les facteurs techniques et économiques. Un investisseur sérieux devrait effectuer des études supplémentairs au niveau de quelques autres facteurs de marché tels que la relation entre les prix et les volumes, les tarifs de retour de camions à vide, avant de procéder à la prochaine étape précédant les décisions d'investissement. Une sélection préliminaire de l'emplacement de l'usine, les essais de matériaux bruts précédant la conception de l'alimentation des matériaux bruts, la spécifications détailée de l'équipement et la vérification du capital et des coûts d'exploitation sont quelques-unes des étapes appropriées que devrait entreprendre un investisseur intéresse.

1.0 INTRODUCTION

Hardy BBT Limited (HBT) was engaged by Supply and Services Canada (SSC) to conduct a Techno Economic Feasibility study for a small scale Portland Cement Plant in Northern Canada. The study was conducted under the auspices of the Canada Centre for Mineral and Energy Technology, Mines and Resources Canada (CANMET). The CANMET Scientific Authority was Mr. A. Lane and SSC Senior Science Procurement Officer was Mr. W. John Humphries.

The study was completed by Hardy BBT Limited under the project management of company's Vice President, Mr. Suresh Gurjar, P.Eng. of the Edmonton office. The Cambrian Engineering Group Limited of Mississauga, Ontario provided sub-consultant services and Mr. Robert D. MacLean, P.Eng. provided specialty consultant services to this study.

The study followed the methodology stated in the Hardy BBT proposal of June 16, 1988. As stated in that proposal, the study focused on the Portland cement markets in The Yukon Territories and the western portion of The Northwest Territories since majority of the economic activities in these Territories requiring use of Portland cement have historically taken place in these areas.

This report includes all the collected information relevant to the study, analysis of the information to determine the feasibility of a small scale Portland cement plant in the market areas described, discussion of the conditions necessary for plant feasibility and concluding remarks

regarding feasibility of setting up a small scale Portland cement plant to satisfy the current needs in the market areas under review.

The cement plant venture may be considered as a long term (20 years) investment decision and will be impacted by many factors included in this study. The current study included many parameters which could be studied in more detail if interest exists for further exploration of this venture.

2.0 SCOPE OF WORK

The majority of economic activities requiring use of Portland cement are currently in The Yukon Territories and the western portion of The Northwest Territories. As a result, the study focused only on the feasibility of a small scale Portland cement operation to satisfy the needs of the markets in these areas of the two Territories.

The work statement by the SSC required that Hardy BBT Limited:

a. Define current uses, major users and suppliers of Portland cement.

b. Define how current users' needs are met ie. who supplies to whom, how and at what price.

c. Predict Portland cement requirements of current and potential users over the duration 1988-2000. Indicate how their needs may be met in terms of sources, transportation methods and prices.

d. Assess the potential for the small scale vertical kiln technology or others to meet the above requirements on a cost competitive basis. Indicate the sources of raw materials, supply methods and cost (capital and operating) needed for such a venture. Indicate any drawbacks to applying the small scale vertical kiln technology or alternatives in this case.

e. Describe the optimum conditions under which the small scale vertical kiln technology or alternatives can be applied to meet the current or predicted Portland cement requirements.

The report essentially has addressed all of the items included in the work statement described above.

3.0 METHODOLOGY

The study was viewed as an exercise in collecting and analyzing information pertaining to

- current demand and supply of cement
- current market areas
- future demand predictions
- transportation of cement
- current total cement costs
- raw material availability in the market areas
- small scale cement plant technology
- small scale cement plant operation
- plant and site requirements
- operating parameters and services
- capital and operating costs

- challenges of cement plant operations in remote areas and harsh climate.

The analysis of these and other items have resulted in determination of the optimum conditions for a small scale cement plant operation and some statements regarding feasibility and further consideration of the venture.

The study has included personal and telephone interviews of the people involved in oil, gas and mining industry associations, exploration industry organizations, various government departments, cement companies, transportation companies, ready mixed concrete companies, northern communities/towns Chamber of Commerce, Chamber of Resources and other similar business organizations. The accuracy of information obtained from these sources can not be readily determined. Many years of experience of the personnel assigned to this study has however, assisted in a reasonable interpretation of the information obtained and the analysis thereof.

To successfully complete the technical requirements of the study, the work was divided into eight (8) separate tasks with a senior member of the study team appointed as a "task leader". The tasks were as follows:

Task 1	Current Uses, Major Users,Suppliers of Portland Cement
Task 2	Meeting Current User Needs
Task 3	Portland Cement Requirements 1988-2000
Task 4	Determination of Raw Material Sources
Task 5	Small Scale Cement Plant Technology

Task 6	Small Scale Cement Plant Operation
Task 7	Analysis, Draft Report, Seminar Presentation, Final Report.
Task 8	Continuous Input to Tasks 1 to 7

The information was collected for analysis through all the task leaders by the project manager. Input was obtained from the specialty consultant on an as required basis. The progress on all tasks was frequently monitored by the project manager.

4.0 USES AND BUYERS OF PORTLAND CEMENT

For the purpose of this study, the term Portland cement included the conventional building construction cement (CSA Types 10, 20, 30, 40 and 50), masonry cement and also "well" cement (Oil well cement) as defined in the American Petroleum Institute (API) Specification 10. The oil well cement is included in the study since it can be (and is being) manufactured using the conventional Portland cement manufacturing technology. Since a small scale cement plant under consideration can possibly manufacture oil well cement as well, the demand for this cement was considered relevant to this study.

4.1 GENERAL USES OF PORTLAND CEMENT

Portland Cement is being used in the Yukon and The Northwest Territories for many purposes as itemized below:

- Concrete used in the construction of structural components such as foundations, walls, columns, beams, slabs; sidewalks, curbs and gutters for road construction in urban centres; precast units such

as medians, curbs, planters, garbage bins, etc. is the major construction product which uses Portland cements of various types.

- Manufacture of precast concrete pipes, blocks and bricks also consume some of Portland cement.

- Portland cement is also being used in the manufacture of concrete, mortar and grouts used in the construction repairs, and rehabilitation projects.

- Portland cement has been also used in the underground mine backfill projects. Portland cement is simply mixed with waste rock material to backfill the already mined areas.

- Oil well cement is being used by oil companies and/or servicing companies during their exploratory and/or production well drilling operations.

4.2 BUYERS OF PORTLAND CEMENT

The major buyers for Portland cement for construction purposes are:

- Ready mixed concrete companies
- Building materials supply outlets
- Resource companies for specific capital projects
- Concrete precast product companies

The buyers referred to above generally buy cement in "bulk" form or in prepackaged 40 kg bags depending on the location of the project,

mode of available transportation and the quantities being purchased. The majority of the cement used in construction is CSA Type 10 (Normal Portland cement). CSA Types 30 (high early) and/or Type 50 (sulphate resisting) are also used on occasional basis.

The oil well cement is used in exploration and production well drilling process and is purchased by Oil companies and/or Oil servicing companies.

The oil well cement is generally purchased in bags or seacan type boxes or in bulk silos, again depending on quantities purchased and project location.

The major cement buyers may be summarized as follows:

- Ready mixed concrete companies - approximate 80 percent of total construction cement
- Concrete precast products companies - approximately 10 percent total construction cement
- Building supply companies - approximately 10 percent to total construction cement
- Oil/Servicing companies - 100 percent of total oil well cement.

5.0 DEMAND AND SUPPLY OF PORTLAND CEMENT

The current demand and supply for Portland cement in the market areas under review was determined simply by interviewing concrete ready mix supply companies, precast product companies, transportation companies, building product companies, oil well servicing companies,

major cement companies, etc. In addition, attempts were made to obtain relevant information from the governments of the two Territories under consideration as well as the government of Canada.

Some problems were encountered during the efforts expended to gather the demand and supply information. Some organizations and companies responded to questions candidly and more openly than others. Many indicated that they had not kept accurate records to be of meaningful assistance. These problems are itemized below:

- Since the demand for Portland cement is not considered a significant item by the government agencies which accumulate and maintain statistical records, there was no historical information available on cement consumption in the market areas under consideration from such agencies. As a result, no significant historical correlations could be established between cement consumption and such relevant items as population, building permits, construction dollar volume, etc.

- Due to the high level of efforts required to gather historical information and the issue of confidentiality, only approximate information could be obtained from competing businesses which buy, supply and use products made using Portland cement. The analysis of the information therefore has required a significant component of judgement and interpretation.

- It became more apparent as the study continued that users, specifiers, engineering community, contractors and a vast majority of those involved in Portland cement use, insist use of Portland

cement meeting recognized ASTM or CSA or API standards. It was felt by those interviewed that use of Portland cement based construction products in the harsh northern climate was already a significant challenge and therefore, use of low to medium grade Portland cement in various construction products may only add to the performance difficulties and raise liability issues in the construction market. Users of Portland cement in underground mine backfill also specify use of CSA or ASTM standard cement. Usage of cement for soil cement construction has been almost non-existent in the past since good granular materials are available for highway and road construction on both The Territories. Furthermore, the specifications most commonly used for soil-cement construction in North America require use of CSA or ASTM Standard Portland cement.

As a results of this concern, use of the vertical kiln plant equipment and technology did not seem feasible primarily on the account of anticipated difficulties of consistently producing ASTM/CSA grade cement. On the authorization by the Scientific Authority, Mr. A. Lane, the efforts were therefore directed to consideration of other small scale cement plant equipment and technologies.

5.1 CURRENT DEMAND OF PORTLAND CEMENT

Portland cement suitable for construction is used for various purpose as stated elsewhere by many entities ranging from "do-it-yourself" handy men to large construction companies. Since it was impractical to reach every possible user to determine cement demand, only major

purchasers, users and suppliers were interviewed to determine the current demand. The total demand was estimated based on the information collected. Following comments are provided regarding the current demand for Portland cement.

- In both Territories, the cement consumption is concentrated in a few well defined settlements/towns/cities/mine locations which are accessible by road and/or water. For example, most of the construction cement in The Northwest Territories is consumed in Yellowknife, Hay River, Fort Smith, Norman Wells, Inuvik, Fort Norman and Fort Simpson. In The Yukon Territories, most of the construction cement is consumed in Whitehorse, Watson Lake, Dawson City, Faro and at specific mine locations.

- Estimated 70 percent of total construction cement in The Northwest Territories is consumed in the Fort Smith region which includes three major urban centres - Yellowknife, Hay River and Fort Smith. Estimated 70 percent of total consumption in The Yukon Territories is consumed in the Whitehorse and surrounding areas.

- Nearly all of Oil well cement consumed in The Northwest Territories is being used in Norman Wells, Inuvik and Beaufort Sea well drilling activities.

- The total steady demand in the market areas under consideration by cement type appears to be as follow:

  CSA Type 10 - about 80 percent of total

CSA Type 30, 50, plus non CSA - about 5 percent of total
API Oil Well Cement - about 15 percent of total

- Those interviewed were specifically asked about the potential use of low to medium grade (Non-spec) Portland cement. Based on the information obtained, there is no demand for such cement since specifiers required CSA/API cement for all the current uses. If demand for non-spec cement exists at all, it is likely to be very, very small, and likely to be well under 1000 tonnes/year.

- About 80 percent plus cement demand in the market areas under consideration is in the peak construction months of May to October.

- The current steady total demand for Portland cement appears to be as follows:

  The Yukon Territories - 7,000 Tonnes/year
  Whitehorse Region - 6,000 Tonnes/year
  The Northwest Territories - 10,000 Tonnes/year
  Fort Smith Region - 7,000 Tonnes/year

  It should be recognized that a part of the cement demand stated above is governed by the activities driven by population growth, and a part is governed by the government and industry special project activities.

5.2 SUPPLIERS AND SUPPLY PLANTS OF PORTLAND CEMENT

The demand for Portland cement in the two Territories under consideration is quite small when compared to the production capacities of the well established cement manufacturing plant in Alberta and British Columbia. Supplying cement to the market areas in The Territories has therefore been an easy task for the Alberta and British Columbia cement companies, since they can meet the demand in these Territories without affecting the supply to the Alberta and British Columbia markets. For example, the smallest cement plant in Alberta and British Columbia produces about 250,000 tonnes of cement per year as compared to the total current steady total cement demand of the two Territories of some 17,000 tonnes per year.

The demand for cement is currently being met by two major cement manufacturers from their manufacturing plants in Alberta and British Columbia. The two major manufacturers are Lafarge Canada Inc. and Inland Cement Limited. Tilbury Cement Limited of Vancouver also supplies some cement to the Yukon market. According to the buyers, their demand for cement is being met in a satisfactory fashion.

The cement for The Yukon Territories market appeared to come mainly from the Richmond and Kamloops cement plants of Lafarge Canada Inc. The cement for The Northwest Territories markets appear to come mainly from the Edmonton plant of Inland Cement Limited, although some is also supplied from the Exshaw plant of Lafarge Canada Inc.

During the interviews it became apparent that there is a certain amount of loyalty built up between buyers and suppliers of cement. The current suppliers are satisfactorily meeting the current needs and are likely to try very hard not to lose their market share in the two Territories under consideration. As a result, a strong possibility exists that the new small scale cement plant may not be able to fully sell cement to the target market areas for a few years after the start of production.

It was also noted that additional excess production capacity exists in each of the Alberta and British Columbia plants currently supplying The Yukon and The Northwest Territories markets.

5.3 TRANSPORTATION AND PRICING OF PORTLAND CEMENT

Supplying cement to the market areas of The Territories has not been a problem in the past. The cost of cement to the purchaser however nearly doubles due to relatively high cost of transportation involving long distances between the cement plants and the consumption locations in The Territories.

The cement is being transported to the market areas of The Territories in the following forms.

Construction Cement

- Bulk Trucks - 80 percent
- 40 kg Bags - 10 percent
- Other - 10 percent

Oil Well Cement

Seacan type boxes and Silos - 95 percent

40 kg Bags - 5 percent

The use of Seacan type boxes and Silos appear to be more common for transportation on barge for specific construction and/or exploration projects. Cement transport in the bulk form (20 tonne trucks) is generally used to supply to relatively large quantity buyers such as ready mixed concrete companies and precast companies in major towns and cities.

The cement is generally being transported to the major concentrated demand areas in the two Territories as follows:

		Approximate Transportation Cost, per tonne
Whitehorse Area - Construction Cement		
From Kamloops:	Kamloops to Fort Nelson by rail	$ 50.00
	Fort Nelson to Whitehorse by road	$115.00
	Total	$165.00
From Richmond:	Richmond to Skagway by water	
	Skagway to Whitehorse by road	
	Total	$140.00
Yellowknife Area - Construction Cement		
From Edmonton:	Edmonton to Yellowknife by road	
	Total	$120.00
From Exshaw:	Exshaw to Edmonton by rail	$ 20.00
	Edmonton to Yellowknife by road	$120.00
	Total	$140.00
Frontier Drilling Areas - Oil Well Cement		
From Edmonton:	Edmonton to Hay River by road	$ 70.00
	Hay River to supply location by water	Appendix A

The approximate cement prices (FOB) are currently as follows. Approximate transportation cost component is also indicated for comparison.

	Per Tonne, Bulk*	Per Tonne, Bags**	Transportation Cost, per Tonne
Yellowknife	$240.00	$295.00	$120.00
Hay River	$190.00	$250.00	$ 70.00
Edmonton	$120.00	$145.00	--
Richmond	$100.00	$135.00	--
Whitehorse	$240.00	$265.00	$140.00

* Excluding Federal sales tax

** Including Federal sales tax

5.4 DEMAND PREDICTIONS OF PORTLAND CEMENT

The total demand for Portland cement has varied considerably in the two Territories over the last five years. The demand for construction cement has been driven by the capital projects undertaken by the governments and industry, as well as by the housing market. The large variation in construction activities is exemplified by the variation in building permit values in The Northwest Territories shown in the "Statistics Quarterly" Volume 10, No. 3, September 1988, published by the Bureau of Statistics, Government of The Northwest Territories. For example, the building permits in The Northwest Territories increased some 11 fold between 1982 and 1985 before dropping in 1986 to 50 percent level of 1985. The building permit values increased considerably in 1985 over 1984 due to large government and institutional spending.

Although there is a steady population growth of about 4 percent per year in the City of Whitehorse and in The Yukon Territories over the last five years or so, the building permit values and the construction values have been somewhat erratic. On the other hand, in some of the outlying towns and/or communities, building permit values have steadily increased in spite of stable population. It is expected therefore that the demand for construction Portland cement will experience a nominal growth somewhat comparable to the population growth with surges of increased demand fuelled by industry and government decisions to proceed with specific projects.

The comparison between population, building permit values, and construction values for The Northwest Territories indicated similar conclusions as those for The Yukon Territories. The population growth in The Northwest Territories has been more modest at about 2.7 percent per year between 1981 and 1986 and relatively stable in 1987 and 1988.

The use of construction cement in mining projects in The Yukon Territories has been erratic. Some backfilling projects are known to require as much as 3,000 to 4,000 tonnes of cement in one single year. The decisions by the mining companies as to their construction projects thus have a significant impact on cement demand from year to year.

Generally speaking, the future demand for construction cement in The Territories will be determined by future construction activities which may be classified as follows:

Housing - fuelled by population growth
Light commercial - fuelled by population growth
Institutional and government - fuelled by government spending
Industrial - fuelled by resource sector spending.

The total demand for oil well cement in The Northwest Territories has also fluctuated very widely. The level of exploration well drilling activities in the Beaufort region both on-shore and off-shore has varied considerably and has reflected in the variation of demand for oil well cement. For example, a major transportation company indicated their shipment figures for oil well cement to have varied from a low of about 500 tonnes/year to a high of about 9,000 tonnes/year during the last 5 years.

The future demand for the oil well cement will be entirely governed by the outlook of the oil companies regarding the world oil prices and the resultant decisions regarding exploration and production well drilling activities.

Due to fluctuating oil prices, low mineral prices and general uncertainties of impact of free trade initiatives of Canada, the primary resource sector industries and others interviewed were unsure about predictions of the economic growth in the designated markets. Future demand for Portland cement is likely to fluctuate more widely than that indicated by such items as trends in population growth. It is

expected that specific large projects and/or surges of exploration and construction activities will cause large increases to the base steady cement demand in the years when these activities occur.

In summary, the historical information on cement demand obtained through interviews indicated that a strong possibility exists indeed that the future demand of cement is likely to vary as widely as it has in the past.

For the purpose of this study, it is assumed that the cement demand of about 7,000 tonnes/year in The Yukon Territories and about 10,000 tonnes/year in The Northwest Territories will grow steadily at approximately the same rate as the population. The demand may however go up rapidly in some years as dictated by government and industry. In addition, a possibility also exists that the cement demand may go up by virtue of the availability of lower priced cement through "local" plants (if one is feasible!). For example, the cement based product may become more attractive compared to the competing products such as steel, the road construction industry may choose to start building concrete roads and use cement for subgrade stabilization, the mining industry may use cement more often than now in their backfill endeavors, etc. Yet another possibility of increased cement demand is presented by the wider acceptance of Roller Compacted Concrete (RCC) for construction of haul roads, lumber yards, large parking areas, etc. in Alberta and British Columbia. It is suspected that experienced contractors may try using RCC in The Territories when opportunity presents itself. The future demands for Portland cement are established as follows:

The Yukon Territories	7,000 to 12,000 Tonnes/year
The Northwest Territories	10,000 to 20,000 Tonnes/year

6.0 POTENTIAL RAW MATERIAL SOURCES

The following basic raw materials are required to produce Portland cement.

- Limestone (major component)
- Clay (can be substituted by other material such as sand)
- Minor components such as gypsum and iron.

The following areas of The Northwest Territories and The Yukon Territories were reviewed for possible raw material sources.

1. Great Slave Plain
2. Mackenzie Valley
3. Mackenzie Delta
4. Whitehorse Area

The reasons for concentrating on these areas are:

- The majority of economic and construction activities occur in these areas.
- These areas are linked to each other and to southern Canada by transportation routes such as highways, railroads and rivers.
- The energy infrastructure exists to connect the cement plant to a power source.
- Limestone, one of the major raw materials for the manufacture of cement, is found in these areas.

It was decided to concentrate mainly on the investigation of potential limestone sources in The Northwest Territories and The Yukon Territories since the presence of glacial clay till and lacustrine clay are common in both The Territories. Limestone is often interbedded with shale, as a result, clay minerals (one of the important raw materials) are likely available in most parts of both Territories. Furthermore, if clay is not available, it can be substituted with another material. A map showing approximate locations of the potential limestone sources described in this section is included as Appendix B.

6.1 GREAT SLAVE PLAIN

This area contains the majority of the population of The Northwest Territories and such major towns as Yellowknife, Hay River, Fort Smith and Fort Simpson. The Great Slave Plain lies between the western mountains at approximately 123°W longitude and the Precambrian Shield.

6.1.1 Surficial Geology

Surficial deposits of the Great Slave Lake area generally consist of glacial and lacustrine clay deposits. Sand and gravel deposits are numerous, particularly in the area between Enterprise and Pine Point. Alluvial deposits of the Slave River occur on the east side of the area. Much of the area is flat lying and poorly drained. Areas of swamp and muskeg are numerous particularly in Wood Buffalo Park and north of the Mackenzie River.

6.1.2 Subsurface Geology

Bedrock in this area consists of Cretaceous sandstones and shales, Devonian limestones, shales, dolomites and evaporites and Ordovician shale, sandstone and dolomite deposits.

a. Cretaceous Deposits

Cretaceous deposits outcrop from plateaus located to the south and north of the region. The Cameron Hills and Horn Plateau rise to an elevation of 840 m above sea level. Cretaceous sandstone and shale are not likely sources of limestone and will not be further discussed in this study.

b. Devonian Deposits

Devonian deposits, consisting of limestone, shale, evaporite and dolomite, are of primary interest to this study. These deposits occur to the south of Great Slave Lake, west of the Slave River and to the north and south of the Mackenzie River.

These deposits are characterized by shallow regional dip and flat topography with few large outcrops. Elevation ranges from 150 m to 380 m above mean sea level.

Outcrops generally occur in gorges of rivers such as the Hay, Kakisa and Trout which flow north into the Mackenzie River or Great Slave Lake. Outcrops also occur along east-west trending escarpments in the area extending from Enterprise to the west of Kakisa Lake.

Spectacular falls such as Louise and Alexandra Falls on the Hay River and Lady Evelyn Falls on the Kakisa River occur where these rivers traverse escarpments.

Potential limestone quarries consisting of Devonian deposits have been identified and are discussed in Section 6.1.3.

c. **Ordovician Deposits**

Ordovician deposits occur on the west side of the North Arm of Great Slave Lake. These deposits outcrop in a belt 50 to 100 km wide trending southeast to northwest from the south extent of the North Arm to the area north of Lac La Martre. These rocks are discussed in Section 6.1.4.

6.1.3 Potential Quarry Areas

Quarry areas must be close to transportation routes and centres of population. River gorges and areas within Wood Buffalo and other parks have been ruled out for environmental reasons. Descriptions of some potential quarries in the Great Slave Plain area follows.

a. **Bell Rock**

Bell rock area is located to the west of Fort Smith. The outcrop consists of aphanitic limestone of the Hay Camp member and gypsum, salt, limestone and dolomite of the Chinchaga Formation. The outcrop is located 240 km southeast of Hay River and is adjacent to the Slave River and Highway No. 5.

This source was not investigated in detail because:

1. Bell Rock marks the north extent of rapids on the Slave River. Historically, it has served as a landmark for boats navigating the river; as a result there would likely be some opposition to quarrying a landmark.

2. Northern Transportation Company Limited (NTCL) had a docking facility in the area adjacent to Bell Rock.

   There is a borrow area for clay to the west of the bell Rock outcrop which could however be considered for supply of clay for cement production.

b. **West of Salt River**

A bedrock area occurs west of the Salt River approximately 20 km west of Fort Smith. It consists of gypsum, salt, limestone and dolomite of the Chinchaga Formation.

There are few large outcrops and numerous gravel deposits in the Salt Mountain area. Some gravel deposits are predominantly made up of limestone. A gravel quarry located 25 km of Fort Smith adjacent to Highway 5 was found to contain 84 percent limestone gravel sizes. (Hardy BBT Limited, 1983, Quarry Management Plan for Three Existing Pits, Salt Mountain Area, Fort Smith, The Northwest Territories).

The described area is approximately 225 km southeast of Hay River and is located near Highway No. 5.

c. **Pine Point Mine Site**

A potential source of limestone could be the waste rock from the now abandoned Pine Point Mine. The minesite rock mainly consists of dolomite of the Presqu'ile Formation and may also contain some limestone waste rock of the Sulphur Point Formation. This rock may be suitable for use in the manufacture of cement.

The advantages of the Pine Point source are:

- The rock has already been quarried
- Pine Point is linked by rail and road to Hay River approximately 100 km to the west.
- Until 1988 there was an existing power supply and infrastructure to the minesite.

The disadvantages are:

- A decision has already been made to shut down the mine and town and reclaim the waste rock. There may be objections to a new industry being located there.
- The waste rock may not be suitable for use in the manufacture of cement. It may also contain some undesirable metallic minerals.
- The Pine Point mine had a high groundwater table, Groundwater had to be pumped out of the pit in the past in order to maintain mining operations.

d. **Grumbler Rapids (km 33)**

The outcrop at this location is either shale/siltstone of the Tathlina Formation or limestone/shale of the Twin Falls Formation. The limestone rock at this location was found to be too shaly and soft for use in highway construction. This rock may be suitable however as a possible raw material for Portland cement.

This site is linked by road and rail to Hay River, approximately 70 km to the north.

e. **Enterprise (km 67)**

DPW & H also has a quarry near Enterprise at km 67 from the Alberta border of the Mackenzie Highway. The outcrop consists of limestone and shale of the Alexandra Member of the Twin Falls Formation. Good quantities of limestone are found south and west of Enterprise on both sides of the highway. DPW & H reportedly use limestone from one side of the highway. This site is linked by road and rail to Hay River, 40 km to the north. Rock from this quarry presents a very good potential as a raw material for Portland cement.

f. **Kakisa River**

An east-west escarpment, paralleled by Highway No. 1, extends from Enterprise west to the Kakisa River. The escarpment consists of limestone outcrops of the Alexandra Member of the Twin Falls Formation. The outcrops are close to the Mackenzie Highway No. 1 and are at a distance from 40 to 100 km west of Hay River.

g. **Kakisa Lake**

Another east-west trending escarpment is located south and west of Kakisa Lake. The outcrops consist of bioclastic, sandy limestones of the Kakisa Formation. The escarpment extends a distance of 50 km southeast of the Mackenzie Highway of approximately 200 km west of Hay River.

h. **Rabbit Lake**

South of Kakisa Lake escarpment, near Rabbit Lake, limestone outcrops of Trout River Formation occur. These outcrops are approximately 10 to 20 km south of the Mackenzie Highway, 200 km west of Hay River. There may be an existing access road to gas wells in the area.

i. **Liard River/Blackstone River**

Bioclastic Limestone - Jean Marie member of the Redknife formation is found east of the Liard River, north of the Blackstone River

approximately 100 km south of Fort Simpson. It appears that there are numerous outcrops in this area.

6.1.4 Yellowknife and Rae Areas

The geology of the Yellowknife area should be discussed separately in the context of setting up a cement plant because Yellowknife, with a population of about 13,000 is the largest city in The Northwest Territories. A great deal of construction activity is presently being carried out in and around the city.

Yellowknife, located on the east shore of the North Arm of Great Slave Lake, is underlain by Precambrian granitic bedrock. There are no potential sources of limestone in the immediate area.

The previously mentioned Ordovician deposits outcrop near Rae-Edzo, about 100 km to the northeast of Yellowknife. A prominent escarpment parallels the North Arm of the lake and trends towards Lac La Martre. La Martre Falls occurs where the La Martre River traverses this escarpment. This escarpment consists of resistant dolomite of the Chedabucto Lake Formation. Limestone outcrops may also occur along the escarpment.

Another less prominent escarpment trends southeast to northwest from Redrock Point on Great Slave Lake to Faker Lake, northwest of Lac La Martre. This feature is approximately 50 km west of the latter and consists of resistant dolomite of the Devonian Fitzgerald, Lonely Bay and Mirage Point Formations. Substantial outcrops of limestone could occur along this escarpment.

6.2 MACKENZIE VALLEY

For the purposes of this report, the Mackenzie Valley covers the region bordering the Mackenzie River from Camsell Bend, 100 km northwest of Fort Simpson, to the Mackenzie Delta. The major towns in the region are Norman Wells and Inuvik. Smaller communities are Wrigley, Fort Norman, Fort Good Hope and Arctic Red River.

Road and water transportation links to the southern Northwest Territories and The Yukon Territories are as follows:

- Barge connecting communities along the Mackenzie River with Hay River
- Winter road from Fort Simpson to Wrigley, Fort Norman, Norman Wells and Fort Good Hope. An all-weather road connects Camsell Bend with Fort Simpson. This road is presently under construction as far north as Wrigley.
- The Dempster Highway, which connects Inuvik and Arctic Red River with The Yukon Territories.

6.2.1 General Geology

The Mackenzie River, on the eastern edge of the Western Cordillera, flows northwest toward the Arctic Ocean. From Camsell Bend to Fort Good Hope, the Mackenzie Valley is bordered by the Franklin Mountains to the north and east, and the Mackenzie Mountains to the south and west. Rock types in the mountain areas are varied. Limestone outcrops in several areas are discussed in Section 6.2.2.

North of Fort Good Hope, the river flows through a plain characterized by low relief and few rock outcrops, which will not be discussed in this report.

6.2.2 Potential Limestone Sources

a. Camsell Bend Area

Limestone of the Devonian Nahanni Formation outcrops along a north - south trending ridge known as the Camsell Range. The ridge, about 3 km in width extends along the west side of the Mackenzie Valley. It is within 5 to 10 km of the Mackenzie River near Camsell Bend but is not accessible by road. It would be accessible by barge from Hay River if appropriate facilities were constructed.

The Nahanni Formation and limestone of the Bear Rock Formation also outcrop further to the north in the McConnell Range on the east side of the river. The McConnell is a north - south trending ridge which extends north from the junction of the Willowlake and Mackenzie Rivers about 40 km north of Camsell Bend. The ridge occurs within 1 km of the Mackenzie River and is from 2 to 5 km in width. The McConnell Range is accessible by winter road from Fort Simpson and by barge from Hay River.

b. Wrigley

The Camsell Range crosses the Mackenzie River north of Wrigley. Mt. Gaudet and Roche Qui Trompe a l'Eau are hills of limestone

belonging to the Camsell Range located north of Wrigley. The McConnell Range continues to the north of Wrigley and consists of bedrock of the Nahanni and Bear Rock Formations. These limestone areas occurring within 6 km of the river, are up to 10 km wide and extend up to 50 km north of Wrigley along the east side of the valley.

The west slope of the Franklin Mountains are accessible by winter road and by barge from Hay River.

c. **Norman Range**

North of Fort Norman, where the Great Bear River meets the Mackenzie River, the Norman Range extends along the northeast side of the Mackenzie Valley. The southwest slopes of the Norman Range include limestone bedrock of the Devonian Hume Formation, Ramparts Formation, and Bear Rock Formation. Numerous outcrops of limestone occur from Fort Norman to Sans Sault Rapids, 100 km north of Norman Wells. In the area of Sans Sault Rapids such features as Beavertail Mountain, Bat Hills, East Mountain and Carcajon Ridge consist of limestone. These areas could be accessed by barge or winter road.

The following two limestone quarries are located in the Norman Range:

i) Norman Wells Quarry - A limestone quarry presently exists a few kilometres to the north of Norman Wells. Limestone of the Ramparts Formation was quarried by Esso Resources for construction of artificial islands in the Mackenzie River.

Norman Wells is the largest community along the Mackenzie Valley and is the site of major oil and gas activity. A Portland cement plant at Norman Wells would have the following advantages:

- An existing limestone quarry
- An existing energy source
- Transportation links - by barge along the Mackenzie River and by winter road to Fort Simpson.

ii) Fort Norman Quarry - A limestone quarry exists near the Bear Rock outcrop located across the Great Bear River from Fort Norman. The rock consists of limestone of the Bear Rock Formation. The area is accessible by winter road or barge.

6.3 MACKENZIE DELTA

Approximately 150 km south of the Beaufort Sea, the Mackenzie Valley broadens into a vast delta bounded by the Richardson Mountains on the west and the Caribou Hills on the east. The Mackenzie Delta is approximately 50 km from east to west at Inuvik.

6.3.1 Potential Limestone Sources

a. Inuvik Area

Inuvik is located on the east edge of the Mackenzie Delta. Limestone of the Precambrian Vunta Formation and the Devonian Gossage Formation occur in the area.

A 1.5 km wide band of the Vunta formation about 12 km in length occurs 5 km south of Inuvik along the Dempster Highway. Larger outcrops of the Vunta Formation occur further to the south in the area between Campbell Lake and the Mackenzie Delta. These larger limestone areas are presently not accessed by a road.

The Devonian Gossage Formation outcrops along the Dempster Highway 18 km southeast of Inuvik and on the east shore of Campbell Lake, 35 km by road from Inuvik. These limestone areas are about 20 km^2 and 5 km^2 respectively.

Two quarries are located in the Inuvik area along the Dempster Highway southeast of Inuvik. Both of these quarries are used by the Department of Public Works and Highways of The Northwest Territories as a source of rock for use in road construction.

i) Near Inuvik Airport - This quarry is located along the Dempster Highway 6 km southeast of Inuvik Airport. Limestone of the Vunta Formation is likely the rock type being quarried at this location.

ii) Campbell Lake - This quarry is located on the Dempster Highway 27 km southeast of the airport on the east shore of Campbell Lake. Limestone of the Gossage Formation is being quarried at this location.

The advantages of a cement plant in Inuvik are:

1. Nearby sources of limestone
2. Transportation routes linking the area to markets in both The Northwest Territories and The Yukon Territories. Inuvik is accessible by barge up the Mackenzie River and by road from the Yukon Territories.
3. Proximity to a centre of population and oil industry market.

6.4 WHITEHORSE AREA

The area within a 100 km radius of Whitehorse is the major population centre of The Yukon Territories. It is served by the Alaska, Atlin and Klondike Highways and by the White Pass and Yukon Railway. Also there is a highway from Whitehorse to Skagway, Alaska. The railroad is used mostly by tourists but could be used by the industry in future.

6.4.1 General Geology

Whitehorse is located within the intermontane belt of the Western Cordillera. The area is characterized by hilly or mountainous terrain overlooking the valleys of the Yukon River and its tributaries. Geology of the mountain areas is extremely varied, ranging from granitic rock to limestone and evaporites.

6.4.2 Potential Limestone Sources

Limestone outcrops in the Whitehorse area belong to one of two formations.

- Limestone and Limestone Breccia of the Upper Triassic Lewes River Group

- Limestone of the Permian and Pennsylvanian Taku and Cache Creek Groups.

6.4.2.1 Outcrops of the Lewes River Group

The following outcrop areas may contain substantial thicknesses of overburden:

a) Canyon Mountain - located across the Yukon River to the east of Whitehorse. The limestone area is approximately 36 km^2. Canyon Mountain is also known locally as Gray Mountain. A large subdivision has been built at the base of the mountain across the Yukon River from downtown Whitehorse. The mountain is easily accessible by a road which leads to a microwave tower at the mountain top. There are no existing quarries on Canyon Mountain.

b) Whitehorse Copper Belt - Numerous open pit mines have been located in what is known as the Whitehorse copper belt. The copper is contained in skarn deposit formed when igneous intrusive

intrusive rock came into contact with limestone wall rock. The mines are located close to the Alaska Highway within 15 km of Whitehorse. These mines are owned by Whitehorse Copper Mines, a subsidiary of Hudson Bay Mining and Smelting.

i) Valerie Mine - Better known as Arctic Chief Pit is located south and west of Whitehorse. The limestone area is approximately 1 km^2. The Valerie Mine area is about 15 km from the Alaska Highway and the White Pass and Yukon Railroad and has an excellent haul road. The waste rock in the pit is white marble and can be seen from quite a distance.

ii) Anaconda Claim - Better known as War Eagle Pit is located 3 km north of Whitehorse. The limestone occupies an area of approximately 1 km^2. The outcrop area is crossed by the Alaska Highway. This open pit is now used as a garbage dump. Garbage would have to be removed before quarrying limestone.

iii) Several smaller pits are located near the Alaska Highway. They are all accessible from the highway and generally consist of limestone waste rock.

iv) Tailings from abandoned mines may also be investigated as a source of limestone for cement.

c) Lansdowne - a village located approximately 50 km south of Whitehorse on the road to Carcross. The limestone outcrop

occupies an approximate area of 2 km². the area is accessed by both the highway and the White Pass and Yukon Railroad.

d) Bennett Lake - Extensive limestone outcrops occur on the east shore of Bennett Lake, just north of Carcross. The area is from 80 to 100 km south of Whitehorse. Limestone occupies an approximate area of 20 km². The east shore of Bennett Lake is served by the White Pass and Yukon Railroad.

e) Lake Laberge - Extensive areas of limestone bedrock occur to the east and north of Lake Laberge, from 30 to 100 km north of Whitehorse. However, these areas are not easily accessible by road and should not be seriously considered as sources of limestone for cement.

6.4.2.2 Outcrops of the Taku and Cache Creek

The following outcrop areas may contain substantial thicknesses of overburden. The Taku and Cache Creek Groups generally occur to the east and south of Carcross.

a) Crag Lake - located east of Carcross approximately 3 km south of the highway from Carcross to Tagish. The limestone occupies an approximate area of 15 km² and is 80 km south of Whitehorse.

b) Mt. White - located southeast of Jakes Corner at the junction of the Alaska and Atlin Highways, 80 km southeast of Whitehorse. The limestone covers an area of about 90 km². Limestone outcrop areas of similar size occur one kilometre to the east of Mt. White

on a neighboring mountain, and to the south extending to the British Columbia border east of the Atlin Highway. There are no existing quarries on Mount White. Limestone of the Taku Group found at Mt. White is less argillaceous and stronger than limestone of the Lewes River Group.

6.5 SUMMARY - RAW MATERIAL SOURCES

6.5.1 Great Slave Plain

Most favorable areas are Enterprise and escarpment areas to the west. Pine Point waste rock should be investigated for suitability in cement. The Yellowknife area is not considered a good source of raw materials.

ADVANTAGES

- Close to Alberta.
- Easier to supply skilled labor and maintain equipment.
- Cost of living for employees is less than Norman Wells or Inuvik.
- Close to road, rail and barge routes.
- Close to Yellowknife.
- Hydroelectric power is available.

DISADVANTAGES

- Long distance from Whitehorse market, about 1600 km.

6.5.2 Mackenzie Valley and Delta

Most favorable areas are Inuvik and Norman Wells.

a) INUVIK

ADVANTAGES

- 1100 km by road from Whitehorse.
- Accessed by barge from Hay River, about 1600 km away.
- Possibly better rates for (backhaul) shipping cement on truck/barge for transport to Hay River, Yellowknife and Whitehorse.
- Existing quarries.
- Can possibly best serve the market areas of interest.

DISADVANTAGES

- High cost of living.
- High cost of construction.
- Shortage of skilled labor.
- High operating and maintenance costs for cement plant.
- High energy costs.

b) NORMAN WELLS

ADVANTAGES

- 800 km by barge from Hay River. Possibly better rates (backhaul) for cement transportation to Hay River and Yellowknife.
- Existing quarries.
- Existing energy source, but may be expensive.
- Possibly better rates (backhaul) for truck from Arctic Red River to Whitehorse markets.

DISADVANTAGES

- 650 km by barge to Arctic Red River and another 1100 km by road to Whitehorse markets.
- Would be paying full rate for barge transport to Arctic Red River.
- High operating and maintenance costs for cement plant.
- High cost of living.
- High cost of construction.
- Shortage of skilled labour.

6.5.3 Whitehorse Area

Possible best sources are:

a) abandoned open pit mines on Alaska Highway.

b) Canyon Mountain.

c) Mount White, about 100 km from Whitehorse.

ADVANTAGES

- Cost of living similar to Hay River/Enterprise.
- Availability of skilled labour is better compared to Inuvik and Norman Wells area.
- Hydroelectric power available and cost may be reasonable due to tax concessions.

DISADVANTAGES

- Long distances to The Northwest Territories markets.

Inuvik	- 1100 km by truck (full rate)
Norman Wells	- 1100 km by truck (full rate) plus 650 km by barge (backhaul)
Hay River	- 1600 km by truck (full rate)
Yellowknife	- 1900 km by truck (full rate)

or via Mackenzie River

Hay River	- 1100 km by truck (full rate) 1600 km by barge (backhaul)
Yellowknife	- 1100 km by truck (full rate) 1600 km by barge (backhaul) 500 km by truck (full rate)

7.0 SMALL SCALE CEMENT PLANT

Production of cement at low rates requires the use of a plant of small scale compared to those commonly built in North America. Contemporary large plants are built to take advantage of economies of scale available in large marketplaces. That is, large scale plants are able to dilute the fixed overheads and to increase paid labour hour efficiencies so that the salary and labour cost component per unit of sales are kept in the region of $12.00 per tonne.

The specifications for Portland Cement by CSA and ASTM permit the storage of cement for up to six months without repeat testing and certification. On this basis, a plant constructed in The Northwest Territories and/or The Yukon Territories should be sized to produce the anticipated steady volume of cement in six to eight months for two reasons. Firstly, seasonal difficulties for blasting, haulage and stockpile reclaim will make interruption in the production on a seasonal basis an operating requirement. Secondly, the large unsteady demand for cement in these territories can only be served by the plant, which operates at a fixed production rate, by continuing to operate for an extended number of days per year.

Additionally, cement plants require periods of shutdown maintenance due to high wear rates for the equipment used for crushing, grinding and burning of the raw materials and the clinker.

For these reasons the raw materials grinding and kiln facilities should be sized to produce the projected steady demand in approximately 200 consecutive working days leaving approximately 120 days for meeting upsurge demand and the balance for shutdown. The clinker grinding facility can be treated in a number of alternate ways. These include matching the plant capacity in anticipation of storing cement in blended finished ground condition, oversizing the finish mill to blend and grind cement of the various type on demand, or undersizing the mill in anticipation of a uniform non-seasonal market for blended cements of the various types.

The plant would therefore be sized to suit the market place or market share in which it is anticipated to operate with a factor of two to accommodate seasonal and additional capacity requirements.

7.1 CEMENT PLANT TECHNOLOGY

This study firstly investigated the use of a continuous vertical kiln for economic production of cement in small volumes. A more detailed discussion of the results of this investigation is shown in Appendix C of this report. The conclusion of this investigation is that the vertical kiln is not a suitable choice for manufacturing cement for consumption in northern Canada. Comments relating to this conclusion also appear in Section 5.0.

The discussion of plant technology in this report therefore pertains to a small scale rotary kiln.

A cement plant proposed for The Territories would be limited to a small plant and would likely operate for a part of the year in the first few years following start-up. With successive years of successful operation, the expansion of both the market size and the market share will result in greater utilization of the annual capacity.

Since the plant capacity will not be initially fully utilized, and since the plant will start-up in a competitive market, and since gross annual costs for fuel in the early years are low and for other reasons discussed later, the plant design should be based upon minimum initial capital equipment purchases and installation. The plant technology will therefore be kept straightforward and equipment, such as a kiln preheater, will be omitted since such equipment is not a requirement for start-up but serves to increase operating plant economies. Such extra equipment items are best examined in the light of more detailed information which would be available after starting the operation.

7.2 CEMENT PLANT OPERATION

The establishment of a cement production facility can be separated into several functions as described in the following subsections.

7.2.1 Acquisition of Raw Materials

a. Limestone

Limestone accounts for approximately 50 percent of plant feed and is required in the proportion of approximately one tonne of ground limestone kiln feed per tonne of cement produced. Provision of limestone can be handled in one of two ways. The first, most direct procedure, is to establish a quarry and hauling facility by the cement plant owner. This requires capital investment in access roads, drilling equipment, magazine and service facilities and the seasonal acquisition of qualified operating personnel, particularly licensed explosive handling personnel.

The second method is to contract with a local and preferably established quarry operator. Since this method would be more capital efficient and would aid the objective of protecting existing infrastructure, this method is assumed for analysis presented in this report. Selection of the plant site and design of the raw feed, however, should be done on the basis of locally available limestone available to the plant from a self-contained quarry for future business planning.

b. Shale

Material, such as shale, with a very high proportion of usable silica, must be available to the plant for kiln feed. Often this shale material also contains additional constituents such as metallic oxides, sulphur, carbon and water. Presence of such constituents requires control or removal of the same to prevent contamination of the clinker and/or

temperature control problems within the kiln. The shale is required in the proportion of approximately one tonne of feed material per tonne of cement produced. This figure, of course, may vary depending on the content of the non-silica constituents in shale and whether cleaning or drying procedures are applied and whether or not these are accomplished within the plant or removed at the shale quarry prior to haulage to the cement plant site.

Again, the cement plant could directly quarry local shale or contract with a local quarry operator for material supplied to site. Similarly to limestone supply, the site selection procedure should include a potential local shale quarry for future business planning.

c. **Gypsum**

Gypsum is added to the cement during clinker grinding at the rate of about 5 percent to modify the setting and curing time of the concrete. This material would be imported and inventoried on site in protected storage.

d. **Iron**

Iron may be added to the kiln feed during preparation to strengthen the hydrated cement. This iron, usually in the form of iron oxide, may be present in the shale in suitable form and quantity to obviate the need for additional contributions to the raw mix. However, frequently the iron is sourced and added to further enhance the raw mix by bringing up to balance one or more of the other constituents which are required in the raw mix. An exact strategy on the handling of iron

must be made during the design of the raw mix; however, for this study, it is assumed that iron oxide will be imported and inventoried in protected storage and fed into the raw mix.

7.2.2 Energy

The cement manufacturing process is a large consumer of energy in two forms. Firstly, of course, large amounts of fuel are required for firing of the kiln to calcine the limestone and to fuse the lime and silica to allow the chemical reactions to take place. This fuel is assumed to be available in the form of heating oil hauled to site and stored in appropriate quantities to provide for possible interruptions of supply.

Oil firing of cement kilns in North America is a well developed technology and can confidently be used for planning of a cement plant. For the preparation of this study, it is assumed that a kiln preheater will not be installed.

The proper functioning of a kiln suspension preheater is a function of many factors including the raw mix constituents which at this point are not fixed. In addition, the supply of a preheater would add substantially to the capital cost of a plant and extend the payback. This item should be reviewed again when more detailed information is available on the extent to which the capital costs could be traded off against the operating costs.

The firing of oil would of course create problems of heat and chemical pollution in the environment. Allowables for capital cost for pollution controls have been included in the cost of the plant.

Oil firing of a plant heating boiler would also be required for heating the operational and service buildings particularly during kiln shutdown.

Substantial amounts of electrical energy are also required for the many large drive motors for crushing, grinding, kiln rotation drive, conveying, etc. Establishing of a cement plant requires a locally available reliable power source with due consideration given to standby generation capable of continuing the kiln in service through a power outage.

7.2.3 Raw Mix Preparation

The kiln will be fed dry material. Dry feed of the kiln has advantages over wet feeding. Dry feeding allows a lower specific energy consumption which is viewed as an advantage throughout the cement industry. Dry feeding also reduces the moisture content on the exhaust gas which reduces operating difficulties in pollution control equipment. The disadvantages of dry feeding are increased wear rates of the raw material grinding equipment and reduced control of the raw material blending. These are not viewed as substantial difficulties for this plant.

7.2.4 Clinker Manufacture

The cement clinker will be produced by burning of the raw materials in a kiln with subsequent cooling of the clinker and silo storage.

7.2.5 Cement Grinding, Storage and Shipping

The cement clinker will be silo stored and subsequently withdrawn, ground, and blended. Finished ground cement may then be either returned to storage or loaded into bags, bulk containers, or tanker bodies for shipment.

7.3 CEMENT PLANT SET-UP AND OPERATION COSTS

Based on the information available for the small scale rotary cement plants, costs of set-up and operation have been estimated. These estimates of costs are presented in a tabular form in Table Nos. 1, 2 and 3 following.

TABLE NO. 1

SMALL SCALE ROTARY CEMENT PLANT
ESTIMATE OF CAPITAL COSTS

F.O.B. CEMENT PLANT SITE, INCLUDING INSTALLATION

	50 Tonnes/Day Plant Millon of Dollars	85 Tonnes/Day Plant Million of Dollars
Raw Material Storage & Handling	1.0	2.0
Raw Materials Grinding	1.0	2.0
Kiln and Cooler	2.0	4.0
Finish Grinding & Blending & Storage	1.0	2.0
Electrical Equipment & Controls	1.0	2.0
Site Preparation, Equipment, Installation and Services	2.0	4.0
Engineering	0.75	1.5
Soils Testing	0.25	0.5
Contingency	1.0	2.0
TOTAL	10.0	20.0

TABLE NO. 2

SMALL SCALE ROTARY CEMENT PLANT
ESTIMATED STAFFING AND ASSOCIATED COSTS

Operations Manager	1 @	$60,000/year
Reception/Bookkeeping	1 @	$40,000/year
Shift Foreman/Control Room Operators (Seasonal)	4 @ $25,000/year	$100,000/year
Mechanical and Electrical Maintenance Staff	2 @ $50,000/year	$100,000/year
Shift General Laborers (Seasonal)	3 @ $20,000/year	$60,000/year
TOTAL ESTIMATED STAFFING COSTS		$360,000/YEAR

TABLE NO. 3

SMALL SCALE ROTARY CEMENT PLANT
ESTIMATED OPERATING COSTS
ASSUMED PRODUCTION - 10,000 TONNES PER YEAR

Materials	Unit Cost ($/Tonne)	Unit Production Cost $/Tonne/Tonne of Clinker
Limestone	13.00	13.00
Shale	5.30	5.30
Iron Ore	150.00	3.00
Gypsum	170.00	8.50
Fuel	--	5.00
Electricity	--	5.00
Operating Supplies	--	2.00
Maintenance Supplies	--	1.50
Material, Sub-Total	--	43.30
Labour, Sub-Total	--	36.00
TOTAL ESTIMATED OPERATING COST		79.30

NOTES:

- Material unit costs are quoted F.O.B. plant site, supplied by established quarry and haulage contractors for limestone and shale materials.
- Unit cost for iron and gypsum are based on importing materials which are reflected in the higher costs.
- Fuel and electricity are based on local costs determined from local sources.

7.4 CEMENT PLANT INVESTMENT ANALYSIS

The economy of a cement plant would be based on the selection of one of the two alternate market strategies considered possible based on the available information.

7.4.1 Norman Wells Cement Plant

The broadest approach would be to erect a plant at a central location, such as **NORMAN WELLS**, to produce cement in quantities to supply the entire Yukon and Northwest Territories markets. This cement would be sold at a uniform price F.O.B. plant and the costs of transportation would be borne by the consumer. This would yield varying local prices depending upon the distance from the plant, the available seasonal transportation methods and rates, and available backhaul rates. This plant is likely to yield consumer savings over imported cement depending on the location and available backhaul rates for transportation. The cement sales volume, if the plant is successful in capturing the full market demand, would range between a steady demand of 17,000 tonnes per year and a peak demand of 32,000 tonnes per year. This market demand is likely to increase if total costs including shipping costs are reduced below current costs.

The investment analysis for the Norman Wells plant is based on assumption of erection of an 85 tonnes per day production capacity plant with cement sale price of $160.00 per tonne, F.O.B. plant. The attached Table No. 4 details the return on investment for this plant.

7.4.2 Yellowknife Cement Plant

An alternate strategy would be to locate the cement plant in or near one of the major consumption centers in The Territories. This would force the plant to operate in a smaller sales volume market due to the increase in transportation costs to remote market areas. Due to small sales volumes, the plant would be required to raise the sale price, F.O.B. plant, to generate the required revenues. Selecting, for example, **YELLOWKNIFE** as the plant location, the plant sales volume would range between a steady demand of 10,000 tonnes per year and a peak demand of 20,000 tonnes per year if it could capture the full market demand. Again demand would increase if sale price is retained at lower than current market sale price.

The investment analysis for the Yellowknife plant is based on the assumption of erection of a 50 tonne per day production capacity plant. Two scenarios are analyzed. In the first scenario described in Table No. 5, the cement sale price has been allowed initially at $240.00 per tonne maximum to correspond with the current sale price. A discount below this price may be offered to increase the cement sales volume. The second scenario described in Table No. 6, shows a return on investment calculation based on a 25 percent discount on the sale price to $180.00 per tonne with an assumed increase of sales volume to 12,500 tonnes per year.

7.4.3 Notes on Investment Analysis of Table Nos. 4, 5, 6

The return on investment cash flow is based on a growth of sales at 2 1/2 percent per year corresponding to the population growth and an inflation rate assumed as 5 percent per year.

The cash flow is calculated as if an established cement company were to set-up a branch plant so that depreciatiion costs would be applied against taxable income.

No allowance has been made for local taxation or capital cost incentives.

One year has been allowed for plant construction and start-up.

The gross sales in the first year have been discounted by 50 percent to allow for operating difficulties and to reflect a takeover of the market by displacement of other sources as current supply contracts expire.

The cash inflow figures have not been discounted to reflect first year dollars.

TABLE NO. 4
INVESTMENT ANALYSIS - NORMAN WELLS PLANT
PRODUCTION CAPACITY - 85 TONNES PER DAY
STEADY DEMAND - 17,000 TONNES PER YEAR
GROWTH RATE - 2.5% PER YEAR
CEMENT SELLING PRICE - $160.00 PER TONNE

Year of Operation	1	2	3	4	5	6	7	8	9	10
Sales Volume (1000 Tonnes/Year)	0.00	8.50	17.00	18.20	18.70	19.20	19.70	20.20	20.70	21.30
Sales, $M	0.00	1.43	2.99	3.38	3.65	3.93	4.44	4.56	4.90	5.28
Costs										
Depreciation Allowance, $M	(2.00)	(2.00)	(2.00)	(2.00)	(2.00)	(2.00)	(2.00)	(2.00)	(2.00)	(2.00)
Expenses, $M	0.00	(1.42)	(1.48)	(1.56)	(1.64)	(1.73)	(1.81)	(1.90)	(2.00)	(2.09)
Taxable Income, $M	(2.00)	(1.99)	(0.49)	(0.18)	0.10	0.20	0.59	0.66	0.90	1.19
Taxes, $M	2.00	1.99	0.49	0.18	0.00	(0.10)	(0.30)	(0.33)	(0.45)	(0.59)
Net Income After Tax, $M	2.00	1.99	0.49	0.18	0.00	0.10	0.30	0.33	0.45	0.59
Depreciation Allowance, $M	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Net Cast Inflow, $M	2.00	1.99	0.49	0.18	0.00	0.10	0.30	0.33	0.45	0.59
Cast Outflow, $M	(20.00)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Payback, $M	(16.00)	(12.01)	(9.52)	(7.34)	(5.43)	(3.24)	(0.94)	1.39	3.84	6.43

TABLE NO. 5
INVESTMENT ANALYSIS - YELLOWKNIFE PLANT
PRODUCTION CAPACITY - 50 TONNES PER DAY
STEADY DEMAND - 10,000 TONNES PER YEAR
GROWTH RATE - 2.5% PER YEAR
CEMENT SELLING PRICE - $240.00 PER TONNE

Year of Operation	1	2	3	4	5	6	7	8	9	10
Sales Volume (1000 Tonnes/Year)	0.00	5.00	10.00	10.25	10.50	10.75	11.00	11.30	11.60	11.90
Sales, $M	0.00	1.26	2.64	2.85	3.07	3.30	3.54	3.82	4.12	4.43
Costs										
Depreciation Allowance, $M	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
Expenses, $M	0.00	(0.83)	(0.87)	(0.94)	(1.02)	(1.09)	(1.17)	(1.26)	(1.36)	(1.16)
Taxable Income, $M	(1.00)	(0.57)	0.77	0.91	1.02	1.21	1.37	1.56	1.76	1.97
Taxes, $M	1.00	0.57	(0.39)	(0.46)	(0.51)	(0.60)	(0.69)	(0.78)	(0.88)	(0.99)
Net Income After Tax, $M	1.00	0.57	0.39	0.46	0.51	0.60	0.69	0.78	0.88	0.99
Depreciation Allowance, $M	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Net Cash Inflow, $M	2.00	1.57	1.39	1.46	1.51	1.60	1.69	1.78	1.88	1.99
Cast Outflow, $M	(10.00)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Payback, $M	(8.00)	(6.43)	(5.04)	(3.58)	(2.07)	(0.47)	1.22	3.00	4.88	6.87

TABLE NO. 6
INVESTMENT ANALYSIS - YELLOWKNIFE PLANT
PRODUCTION CAPACITY - 50 TONNES PER DAY
STEADY DEMAND - 12,500 TONNES PER YEAR
GROWTH RATE - 2.5% PER YEAR
CEMENT SELLING PRICE - $180.00 PER TONNE

Year of Operation	1	2	3	4	5	6	7	8	9	10
Sales Volume (1000 Tonnes/Year)	0.00	6.25	12.50	12.80	13.10	13.40	13.75	14.10	14.50	14.90
Sales, $M	0.00	1.18	2.48	2.67	2.88	3.09	3.32	3.56	3.86	4.16
Costs										
Depreciation Allowance, $M	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
Expenses, $M	0.00	(1.04)	(1.09)	(1.18)	(1.28)	(1.36)	(1.46)	(1.58)	(1.70)	(1.83)
Taxable Income, $M	(1.00)	(0.14)	0.39	0.49	0.60	0.73	0.86	0.98	1.16	1.53
Taxes, $M	1.00	0.14	(0.20)	(0.25)	(0.30)	(0.36)	(0.43)	(0.49)	(0.58)	(0.67)
Net Income After Tax, $M	1.00	0.14	0.20	0.25	0.30	0.36	0.43	0.49	0.58	0.67
Depreciation Allowance, $M	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Net Cash Inflow, $M	2.00	1.14	1.20	1.25	1.30	1.36	1.43	1.49	1.58	1.67
Cash Outflow, $M	(10.00)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Payback, $M	(8.00)	(6.86)	(5.66)	(4.41)	(3.11)	(1.75)	(0.32)	1.17	2.75	4.42

8.0 FEASIBILITY STATEMENTS

Set-up and operation of a Portland Cement Plant is a venture which requires a large capital investment commitment, a high level of expertise during the set-up process and continuous technical expertise for successful operation and production of good quality cement. This study was mainly focused on the supply-demand issues, transportation issues and finally the economic issues associated with set-up of a small scale plant. While many factors associated with feasibility decisions were reviewed in this study, a serious investor no doubt will have to engage in a more thorough determination of factors such as price-volume relationship, specific back haul or regular transportation rates, quality of specific raw material and proportions required thereof, F.O.B. plant costs for specific raw material from a specific source, the back-up support for plant equipment operation, maintenance and repairs, site selection based on geotechnical considerations, electricity hook-ups and fuel availability, and so on.

A number of possible side effects resulting from the set-up of a cement plant in Territories were noted during this study. The impact of the items stated below was not explored.

- A local cement plant would keep about $3.0 to $4.0 million per year in the local economy.

- Generally there is a shortage of skilled and specialized labour in Territories. Additionally, support for such items as equipment and repairs may also be more difficult in Territories

as compared to other major Canadian cities. The cement plant set-up may help create new expertise in the north.

- The Alberta and British Columbia transportation companies specializing in transportation of cement to the northern communities in the Territories will be adversely affected if a cement plant is set-up in the north.

- A cement plant in the north will also have an impact on the profitability of the current cement suppliers.

- A cement plant in the north will have a positive impact on the transportation companies specifically servicing on the inter-community routes.

- On a long run, a cement plant will also have a positive impact on mining/quarrying operations as these relate to recovery of chosen raw materials.

In the following subsections, statements are made in a broad sense on the necessary feasibility conditions for a cement plant set-up. These are followed by an overview of the existing conditions leading to the feasibility conclusions.

8.1 NECESSARY FEASIBILITY CONDITIONS/ENVIRONMENT

To make a small scale cement plant a feasible business, the cement market would have to be stable and several times larger than that currently present.

For economic success, the plant must be able to generate larger profit margins by achieving much greater dilutions of labour and overheads over the cement sales volumes. For successful and efficient business planning, the spread between the consistent demand and peak demand, currently at about 100 percent, should not be so large. The peak demand in the current situation is also generated largely by resource industries, making the prediction of this market difficult.

Market surveys while indicating high prices paid for cement have not indicated a shortage of cement supply, thus signaling that a new plant established in the north may find itself in a price discount competition with the current cement suppliers. Such is obviously not a desirable condition.

The improvement of transportation systems in the north, while giving the initial appearance of making a larger market available to the plant, would similarly make those markets more readily available to producers in the south and may put the northern small scale plant squarely in an undesirable competition with the southern plants.

8.2 OVERVIEW OF THE EXISTING CONDITIONS

Review of the investment analysis and cast flows indicated that a small scale plant would have a long payback even in a very attractive total market share takeover position. Additionally, building of a plant with a view to creating an increase in total market by making the substitution of Cementitious construction over other construction methods does not appear attractive.

For the purpose of the economic analysis, a linear relationship between the cost of cement and the volume of replacement market available has been assumed. This discounting of the price leads to a drop of gross margin which is not completely replaced by increase in the market share, leading to a reduction of payback funds.

The major observations of this study is that operating costs, particular the labour costs, are high per unit of sales. Typically large plants centered in large markets are able to keep unit production costs to approximately 40 percent of the local sale price of cement. A small scale plant in the North would not be able to generate profit margins similar to those plants operating in a location which yields either a large enough local market or economically competitive access to large markets.

The existing marketplace is relatively very small compared to production capacity in the south leaving producers and transportation companies in the south currently supplying the northern markets in a position to engage in a price competition with a new proposed plant in the north. This factor also leaves establishment of a plant in the north in vulnerable circumstances. The lack of large profit margins and the sensitivity to market share would prohibit the plant from engaging in such price competitions either imposed by other producers or initiated from within.

8.3 FEASIBILITY CONCLUSIONS

The foregoing study has yielded two major conclusions.

a. The payback period is too long compared to other investment opportunities available both in the cement industry and in many other industries.

b. The viability of the plant is vulnerable to market factors; size, penetration and competition.

8.4 FUTURE ACTIONS

The fundamental question at this stage is of course to determine further courses of action. The following items may be considered:

a. Attempt to interest and involve a currently operating cement manufacturing company to take expertise.

b. Select a site for the plant based on some demonstrated interest within the industry.

c. Acquire samples of locally available raw materials, limestone and shale, and submit these for laboratory testing for design of the raw feed.

d. Specify in detail the equipment and verify capital and operating costs based on the raw mix design.

e. Engage in an in-depth determination of the market factors stated earlier in Section 8.0.

APPENDIX A

Freight Rates
Mackenzie River Barge

northern transportation company limited

TARIFF EXTRACT

1988 Cargo Rates
Rates in Cents per 100 lbs. (Includes Terminal Charge of 40 cents per 100 lbs.)

(Goods not listed herein subject to classification and/or minimum weights)

FROM HAY RIVER TO:	Furniture and Appliances Personal Effects	Light Duty Vehicles Subject to Min. Weights	General Merchandise Single Lot Shipments of Less Than 40,000 lbs. Subject to Minimum Weights	General Merchandise Single Lot Shipments of Minimum Weight of 40,000 lbs. Subject to Minimum Weights	Minimum Charge
Aklavik	1968	1486	1004	908	$30.50
Arctic Red River	1874	1416	957	865	$30.50
Fort Good Hope	1552	1174	796	720	$30.50
Fort Norman	1304	988	672	609	$30.50
Inuvik	1912	1444	976	882	$30.50
Jean Marie River	1008	766	524	476	$30.50
Norman Wells	1304	988	672	609	$30.50
Snowdrift	1344	1018	692	627	$30.50
Reliance	1510	1143	775	702	$30.50
Tuktoyaktuk	2212	1669	1126	1017	$30.50
Wrigley	1210	918	625	567	$30.50
Bathurst Inlet	4336	3262	2188	1973	$42.96
Bay Chimo	4280	3220	2160	1948	$42.40
Cambridge Bay	4336	3262	2188	1973	$42.96
Coppermine	3946	2970	1993	1798	$39.06
Gjoa Haven	4772	3589	2406	2169	$47.32
Holman	3294	2481	1667	1504	$32.54
Paulatuk	3084	2323	1562	1410	$30.50
Sachs Harbour	2940	2215	1490	1345	$30.50
Spence Bay	4966	3735	2503	2257	$49.26

MINIMUM WEIGHTS

1. Trailers, modules, mobile buildings, set-up storage tanks exceeding 4,500 litres and similar bulky items subject to minimum weight of 150 lbs. per square foot of barge space occupied. Measurement will be governed by widest width and longest length.
2. Lightweight items such as insulating materials, small fibreglass storage tanks not exceeding 4,500 litres, set-up culverts and prefabricated items (such as trusses, wall panels and set-up cabinets) subject to minimum weight of 15 lbs. per cubic foot. Measurement weight will be calculated using extreme overall dimensions of each package or unit.
3. Vehicles: Up to 15 feet overall length - min wt 3000 lbs
   15 to 18 feet overall length - min wt 4000 lbs
   18 to 20 feet overall length - min wt 5000 lbs
   over 20 feet add 500 lbs per foot or fraction thereof

GENERAL MERCHANDISE

General merchandise includes such items as foodstuffs, drygoods, building material, hardware, lumber, crated motorcycles and all terrain vehicles, crated snowmobiles and sporting goods.

APPENDIX B

Approximate Location of Potential Limestone Sources

Potential Limestone Sources

LEGEND

⊕ Limestone Quarries

1. Enterprise - km 67 - Mackenzie Highway
2. Fort Norman - Bear Rock
3. Norman Wells
4. Inuvik - Dempster Highway
5. Inuvik - Dempster Highway
6. Whitehorse - Open pit copper mines

Limestone Bedrock

6. Whitehorse Canyon Mountain
7. East of Lake Laberge
8. Lansdowne
9. Bennett Lake
10. Crag Lake
11. Mt. White
12. Norman Range
13. McConnell Range
14. Camsell Range
15. Rabbit Lake
16. Kakisa Lake Escarpment
17. Kakisa River Escarpment
18. Grumbler Rapids - km 35 - Mackenzie Highway
19. Salt Mountain area - Fort Smith

- - - - ..... Geological Features

20. Escarpment - Faker Lake to Redrock Point
21. Lac La Martre Escarpment

Limestone Bedrock

22. Outcrops along Liard River and Liard Highway
23. Outcrops along Liard River and Liard Highway

MACKENZIE MOUNTAINS
YUKON TERRITORY
MACKENZIE
Mackenzie R.
Yukon River
Tanana River
Porcupine R.
Peel R.
Liard
Slave River
Great Slave Lake
Great Bear Lake
Horton River
Anderson R.
Hornaday River
Coppermine R.
Richardson Mts.
Wrangell Mts.
Alaska
B-2

APPENDIX C

Vertical Shaft Kilns

VERTICAL SHAFT KILNS

The vertical shaft kiln, sometimes called automatic shaft kiln or continuous shaft kiln, is a simple vertical stationery tube into the top of which is introduced a mixture of raw materials, plus a solid fuel in the form of coke, and sufficient water to allow the feed to be briquetted or pelletized. The raw mix is burnt to a clinker as it descends within the kiln and an automatic discharge arrangement withdraws the burnt clinker at the bottom.

The vertical shaft kiln has found favor in various parts of the world for locally important reasons. It has in the past been more popular than rotary horizontal kilns in Europe because of the wide availability and lower cost of coal and coke fuel. It has been used in underdeveloped nations because of the simplicity and low cost of local fabrication and availability of abundant and low cost labour for clinker sorting.

However, these factors cannot be applied to the market areas under consideration.

There are several other potential drawbacks to the vertical shaft kiln. These include the difficulty of start-up and shutdown procedures envisaged, the lack of available used equipment which could be incorporated into a new plant at substantial savings and the lack of quantities of hot off gases which are used for drying and classification during grinding.

As outlined in the responses to our inquiries attached, the vertical shaft kiln is not a suitable choice for the intended cement production. Other factors supporting this conclusion are stated in Sections 5.0 and 7.1 of this report.

the cambrian engineering group limited

2200 Argentia Road
Mississauga, Ontario
Canada L5N 2K7
Telephone: (416) 858-8010
Telex: 06-218797
Telefax: (416) 858-3332

January 10, 1989

D35.10

Portland Cement Association
5420 Old Orchard Road,
Skokie, IL,
60077,
U. S. A.

Gentlemen:

We are seeking information on the current state of the technology for manufacturing cement using vertical kilns. Our specific concerns include:

1. Can vertical kilns produce cement of a quality level to meet or exceed ASTM Standards.

2. If the cement product does not meet ASTM Standards can it be produced to meet some other uniform standard or manufacturer's quality assurance level.

3. What capacity range is practical for vertical kiln cement production.

4. Are there any institutions or manufacturers developing or marketing vertical kiln units in North America or Europe at the present time.

Your earliest response to this inquiry would be very much appreciated.

Yours very truly

THE CAMBRIAN ENGINEERING GROUP LIMITED

Gerry Shessel
Mechanical Design Engineer.

GS:tmcc

The Cambrian Engineering offices are in MISSISSAUGA SASKATOON OTTAWA TIMMINS

CTL
construction technology laboratories, inc.

5420 Old Orchard Road, Skokie, Illinois 60077-1030 • Phone 312/965-7500
Telex 9102401569 CTL.SKO • Easylink: 62200170 • Facsimile 312/965-6541

January 25, 1989

Mr. Gerry Shessel
The Cambrian Engineering Group, LTD
2200 Argentia Road
Mississauga, Ontario L5N 2K7
CANADA

Dear Mr. Shessel:

Your inquiry concerning vertical kilns addressed to the Portland Cement Association has been forwarded to me for handling.

There is not a great deal of information on the operation of vertical cement kilns, particularly since the only modern vertical kiln in the United States ever to be run was shut down in the early 1960's. I do not believe that Canada ever had a modern vertical kiln. To my knowledge, all of the modern vertical kilns in Europe have been shut down also. However, we do have some information which I can impart to you in order to answer each of your questions to some small extent.

Question 1. The answer depends upon what one means by exceeding ASTM standards. If one means strength standards, then almost any process can exceed these standards since they are set very low. If one means meeting market demands, then I believe we have to know and understand which market, in what country, we are dealing with. Probably, uniformity will be less than with a rotary kiln plant, sulfur compounds may be troublesome, rate of strength gain may be inferior to those of rotary kiln-produced cements. But, as I said, it would depend on what market one was selling in.

Question 2. If the market is Canada or the United States (and some South American countries), ASTM Standards have a quasi-legal status in the courts, and also almost all cement is ordered on the basis of Canadian Standards Association or ASTM specifications. One has a hard time selling cement that does not meet these standards in these countries. You did not say in your letter what country you might be operating, so I cannot comment further.

Question 3. The last modern vertical kilns I have first hand knowledge of produced about 70,000 tons per year, and I believe these kilns were typical of the state of the technology. There are inherent limitations to the capacity of vertical kilns.

Question 4. I know of no one manufacturing vertical cement kilns in North America or Europe at this time. The last people who did so, to my knowledge, was a company in Switzerland, the DeRoll Company. I do not know if they are still in business.

I hope this information will be useful to you.

Sincerely,

Stewart W. Tresouthick
Director
Chemical/Physical Research Dept.

SWT/jav

HA3003

the cambrian engineering group limited

2200 Argentia Road
Mississauga, Ontario
Canada L5N 2K7
Telephone: (416) 858-8010
Telex: 06-218797
Telefax: (416) 858-3332

December 21, 1988

D35.10

American Concrete Institute
Post Office Box 19150
Redford Station
Detroit, Michigan,
48210-0150
U. S. A.

Gentlemen:

We are seeking information on the current state of the technology for manufacturing cement using vertical kilns. Our specific concerns include:

1. Can vertical kilns produce cement of a quality level to meet or exceed ASTM Standards.
2. If the cement product does not meet ASTM Standards can it be produced to meet some other uniform standard or manufacturer's quality assurance level.
3. What capacity range is practical for vertical kiln cement production.
4. Are there any institutions or manufacturers developing or marketing vertical kiln units in North America or Europe at the present time.

Your earliest response to this inquiry would be very much appreciated.

Yours very truly

THE CAMBRIAN ENGINEERING GROUP LIMITED

Gerry Shessel
Mechanical Design Engineer.

GS:tmcc

The Cambrian Engineering offices are in MISSISSAUGA SASKATOON OTTAWA

313-532-2600
TELEX 230 2211454
TELEFAX 313-538-0655

american concrete institute

BOX 19150
[illegible] MILE ROAD
[illegible] MICHIGAN 48219

January 3, 1988

Mr. Gerry Shessel
Mechanical Design Engineer
The Cambrian Engineering Group Ltd.
2200 Argentia Road
Mississauga Ontario
CANADA L5N 2K7

Dear Mr. Shessel:

Thank you for your letter of December 21, 1988, requesting information on manufacturing of cement using vertical kilns. Unfortunately, we do not have the information you request.

I suggest that you contact the Portland Cement Association. Their address is:

5420 Old Orchard Road
Skokie, IL 60077

Sincerely,

James Dikeou

James T. Dikeou, F.A.C.I.
Staff Engineer

JTD:jt

the cambrian engineering group limited

2200 Argentia Road
Mississauga, Ontario
Canada L5N 2K7
Telephone: (416) 858-8010
Telex: 06-218797
Telefax: (416) 858-3332

December 21, 1988

D35.10

F. L. Smidth & Co. A/S
DK - 2500,
Valby
Copenhagen,

Denmark

Gentlemen:

We are seeking information on the current state of the technology for manufacturing cement using vertical kilns. Our specific concerns include:

1. Can vertical kilns produce cement of a quality level to meet or exceed ASTM Standards.

2. If the cement product does not meet ASTM Standards can it be produced to meet some other uniform standard or manufacturer's quality assurance level.

3. What capacity range is practical for vertical kiln cement production.

4. Are there any institutions or manufacturers developing or marketing vertical kiln units in North America or Europe at the present time.

Your earliest response to this inquiry would be very much appreciated.

Yours very truly

THE CAMBRIAN ENGINEERING GROUP LIMITED

Gerry Shessel
Mechanical Design Engineer.

GS:tmcc

The Cambrian Engineering offices are in MISSISSAUGA SASKATOON OTTAWA

F. L. SMIDTH & CO.
300 Knickerbocker Road, Cresskill, N.J. 07626, U.S.A.
Telephone: (201) 871-3300
Telex: 178088 (FLS CRESS) Telefax: (201) 569-8525

F. L. SMIDTH

Your ref. | Your letter of | Our ref. PJR/EMPo | Date February 8, 1989 | Page 1

The Cambrian Engineering Group Limited
2200 Argenia Road
Mississauga, Ontario
Canada L5N 2K7

Attention: Mr. Gerry Shessel
Mechanical Design Engineer

Gentlemen:

Subject: Vertical Kilns

In response to your letter to our parent company in Copenhagen, Denmark, we are providing a paper entitled "Mini Cement Plants", which describes basic information and a description of vertical kilns.

Also included is a paper, published by Zement-Kalk-Gips in 1984, entitled "Semen Kupang, A Modern Shaft Kiln Cement Works on the Island of Timor, Indonesia".

Very truly yours,

F. L. SMIDTH & CO.

Paul J. Riley
Sales Manager
Cement Industry

enc.

UNA2953

MINI CEMENT PLANTS

Paper prepared by Mr. S. Hundebøl

of

F.L.SMIDTH & CO. A/S, Copenhagen, Denmark

in connection with visit from

Ceramic Industries Corporation-Burma

December 1987

Mini Cement Plants.

With regular intervals the question about mini-cement plants comes up. People knowing the structure of developing countries feel that large cement plants as we know them today may not be the right solution. The rather small needs of a rural region should be covered by a small local plant, erected and operated by local people. Certainly we can mention several reasons for avoiding the large units:

Investment sum of a small unit is lower.

Distribution problems due to poor infrastructure.

Small units create jobs. Machinery can be made by local skilled workers, or at least repaired by them, and the operation of the plant may require a large force of unskilled and skilled workers.

In the following we shall try to comment on the technical issues concerning mini-cement plants. By a mini-cement plant we do not understand a modern factory, that has been scaled down. Such a plant would be tremendous expensive pr. ton produced. The focus will be on primitive simple, rugged technology.

Historical Outline

It is generally suggested, that the developing countries should go through the same evolutionary process as the European countries did 50 or 100 years ago, therefore we may take a closer look at the history of cement production.

Cement manufacture started back in the 1820'es. The kilns were primitive and small. About chemistry the operators knew nothing. They managed to produce cement only by empirical rules and recipes (which went: Take 4 barrels of limestone and 1 barrel of clay, and a shovel full of sand and two shovels of coke. Mix carefully and grind it for 1 hour in the horse-driven mill. Nodulize to balls of 2 inch size). Kiln operation was based on what the operator could feel with his hands or smell. The clinker was sorted carefully by hand (e.g. throw any yellow lumps away, and the larger heavy black lumps). Finally the selected clinker was ground in a ball mill. Consumers of cement were told to use plenty of it when preparing the concrete - and not too much sand and gravel. Otherwise there would be no guarantee that the house or the bridge would not collapse. As you may see, it was manhour consuming to produce cement and an art more complicated than French cuisine. Cement was comparatively expensive in those days.

The founder of this company, Mr. F.L.Smidth, started during the shaft kiln period. What made him famous was his inventions of reliable ball mills driven by electrical motors - and the introduction of the rotary kiln.

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Although the rotary kiln consumed the same amount of fuel as the shaft kiln, it soon became a hard competitor, since the product quality was more uniform; the strengths were higher, and there was very little loss of underburned and overburned clinker.

Rotary kilns had one advantage more: They could be made bigger, 500 tpd was perhaps the mean size around the second World War. Shaft kilns never grew bigger than 200 tpd. From around 1960 the cyclone preheater was introduced, and around 1970 the precalcining technique. This boosted the capacity of kiln installations further. Today the mean size is 3000 tpd, with practically no kilns below 1000 tpd. Cement manufacture has been perfected to an optimum of product quality and energy consumption is lower than any time previously.

Basics about shaft kilns

It is rather evident that a mini cement plant should be based on the shaft kiln. It contains less moving parts than a rotary kiln and so it is easier to fabricate locally. The kiln is, however, not the only essential part. What about raw material preparation and comminution of clinker, can we do without the mills - ball mills or vertical mills found in the large cement plant?

The answer is no. And this is perhaps the biggest mistake the devotees of the mini cement plants make.

The requirements of a careful raw meal preparation including exact dosage of raw materials, mixing and comminution are the same for the rotary kiln and the shaft kiln.

Why? Simply because if you don't adjust the composition to be within the limits allowed for the lime saturation factor, silica module, and the alumina module, sound cement cannot be produced. And if you do not grind the raw materials sufficiently, you cannot burn the clinker to a low content of free lime within the time available. The rule is: Garbage in = garbage out. And this rule holds true for both rotary kilns, and shaft kilns.

Likewise it is obvious that the clinker must be ground to cement powder. The question is, whether clinker from a shaft kiln can be more easily ground than clinker from a rotary kiln. This need not be the case. Chemically, and by structure, the two clinker types are very similar and they require nearly the same input of electrical energy.

The flow sheet of a cement plant is thus fairly complicated even with a shaft kiln.

What you do is to take raw materials - and hopefully you have dry materials - and mix them in the right proportions. The fuel to be used - which can be charcoal, or coke breeze or anthracite - is mixed into the raw materials at this stage (here you have decided what heat economy to apply).

The mixture of limestone, shale, clay, sand, ashes or whatever you need and the solid fuel must be very carefully ground to a fineness at least 90% < 90 microns.

The resulting powder, which we may call black meal due to its content of black char or coal, is then further blended and mixed in silos.

The black meal is thereafter pelletized with water on a rotating nodulizer. Balls of size 15-25 mm are desirable. This may require the addition of up to 18% water.

The pellets are then transported to the shaft kiln, to be burnt to clinker.

The shaft kiln is a very simple machine. A 200 tpd kiln is typically 8-10 m high and of a diameter of 2.4 m. The pellets are introduced at the top and distributed evenly by a rotating distributor. Then the pellets move slowly downwards, and get dried, preheated and calcined counter-current with the smoke gases. At some point down the kiln the coke ignites. The pellets get completely calcined, further heated and partially melted. The clinker minerals form. When the coke has disappeared, the cooling of the clinker starts countercurrent with the air. The entire column of pellets and clinker rests on the bottom grate. In this case the grate is conical, resembling a christmas tree. The grate turns slowly, and as it does so, clinker are continuously scraped out and leave the kiln through an air lock. The air is blown into the shaft through the grate by a compressor. The smoke gas from the kiln leaves at the top and is conducted to the chimney.

After appropiate hand-sorting of the clinker, the clinker is mixed with 5% gypsum and ground to cement in a ball mill.

The flow sheet of the conventional plant is different with respect to the following: During the grinding step, raw materials are dried in the mill with the off-gases from the kiln system. The dry raw meal is introduced directly without adding water. Coal is ground in a separate mill, and the burning process is regulated by adjusting the coal flow (the shaft kiln cannot be regulated this way, only the air flow/feed rate ratio can be altered if the kiln is too hot or too cold, the fuel to feed ratio is fixed during the milling and process).

Heat economy of a shaft kiln

It is often claimed that the shaft kiln is more economical than a conventional system, but this statement is not true anymore. Even the best shaft kilns consume 850 kcal/kg cl. on their best days, and don't be surprised if you hear about 1100 kcal/kg cl. The heat economy of a modern rotary kiln with preheater is almost always better than 800 kcal/kg cl, and 735 kcal/kg cl. can be achieved.

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It is true, that smoke gases and clinker leave the shaft kiln at a very low temperature - but energy is wasted in other ways.

A high loss of energy is due to the fact that the flue gas contains typically 5% CO - and there is very little you can do about that. For the evaporation of the water a considerable amount of calories is spent. To form pellets of a sufficient strength a certain percentage of water is required, so you cannot make this loss smaller without making the kiln inoperable.

Due to these two losses, the economy is rather poor. A heat economy of 850 kcal/kg kl. even assumes that the raw materials are bone dry: There is no hot smoke gas available for drying the raw materials in the raw mill.

The power consumption of a shaft kiln

There is a considerable pressure drop over a shaft kiln, and it may be demonstrated that a simple fan cannot suck the air through the shaft. Thus a fairly heavy air compressor (e.g. a single stage centrifugal compressor or a Roots blower) must be supplied - and this machine cannot be made by the local blacksmith.

See the following calculation example for a standard size 180 tpd kiln. The pressure drop is in the order of 1600 mmWG - and this value may increase further if the porosity of the charge drops due to less efficient pelletizing. The electrical energy consumption of the blower comes into the range of 6 kWh/ton cl., which is the same or more than the fans of the conventional system spend.

Operational Trouble

Say we have prepared the raw meal and the pellets very carefully, can we then expect the operation of the shaft kiln to be trouble-free?

It is generally recognized, that this is not the case, since there is one break-down possibility always threatening the stable operation: If the air distribution becomes skew, things will get worse, and clinker quality be much impaired.

There is a tendency for the pellets in the central core to be more compressed than the pellets near the wall. If a core of a little lower porosity develops, the air will distribute itself in such a way that the regions near the wall get too much air, and the central core too little. This explains why the smoke gas contains CO and O_2 at the same time. Moreover, the clinker of the central core will be cooled at a slow rate, under reducing conditions. This will destroy these clinker particles, since the C_3S of them will have time to go back to C_2S and free CaO, and Fe_2O_3

will be reduced to FeO. The cement of this high-density clinker will certainly be very unsound.

Once the shaft kiln starts to produce these unsound clinker, there is no way of return. You have no means of correcting the error, except shutting down, emptying the shaft, and starting again.

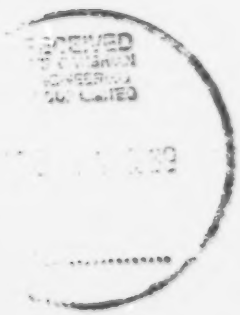
Conclusion

Although it sounds very promising to build mini cement plants with a shaft kiln as the basic unit, a lot can be said against it. Above all, the machinery does not get so simple: There is no way around buying a raw mill for grinding the raw materials. A cement mill is also necessary. The shaft kiln is simple, but at least a fairly heavy air blower is required. Heat and Energy Consumptions are not lower pr. ton of cement produced, they are generally higher. Analyzing the raw materials and the raw meal is still indispensable, although an expensive x-ray analyzer is not necessary, but simple chemical analysis is required.

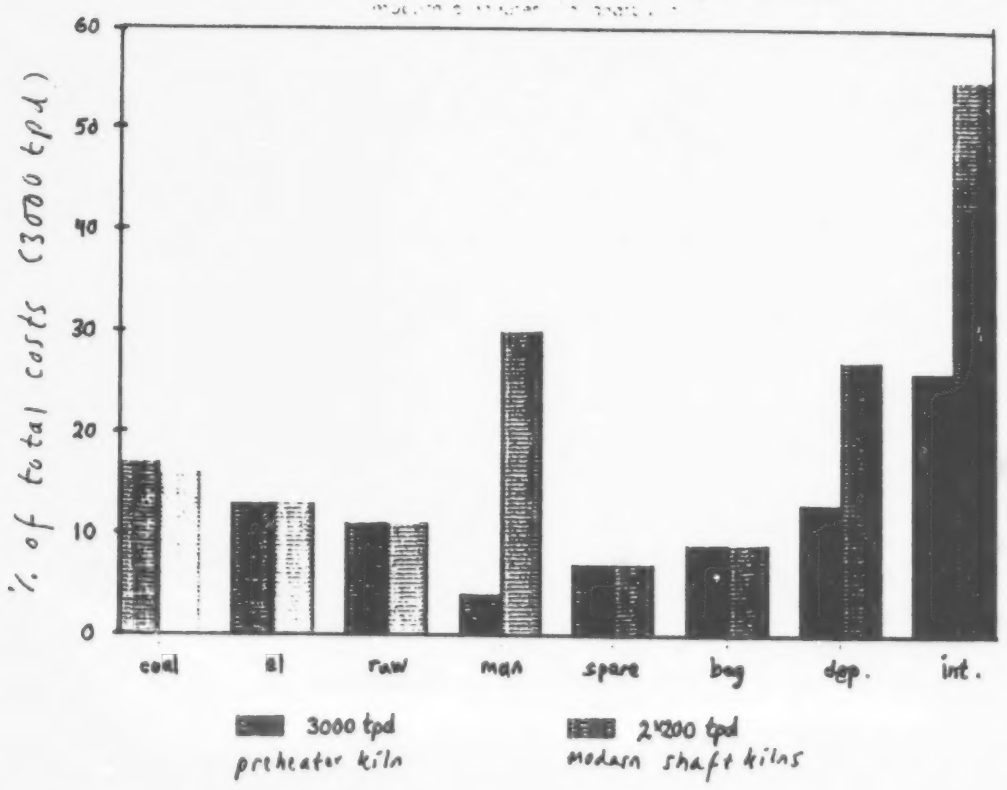
What is left to be said in favour of it, is that the investments per unit are lower and perhaps even the investment per tons per day will be lower. Some parts of the factory can be produced locally. Quite a long row of transport and dosage apparatus can be omitted in the first place. Instead these functions must be performed by workers with simple tools. By the same token, computers are not necessary. Calculations can me made manually. And finally, a mini cement plant erected by the local people themselves may contribute very much to their self-confidence and induce them to make further progress.

Why build Mini Cement Plants?

1. Low investment
2. Lack of infrastructure
3. Creation of jobs
4. Transfer of skilled workers technology

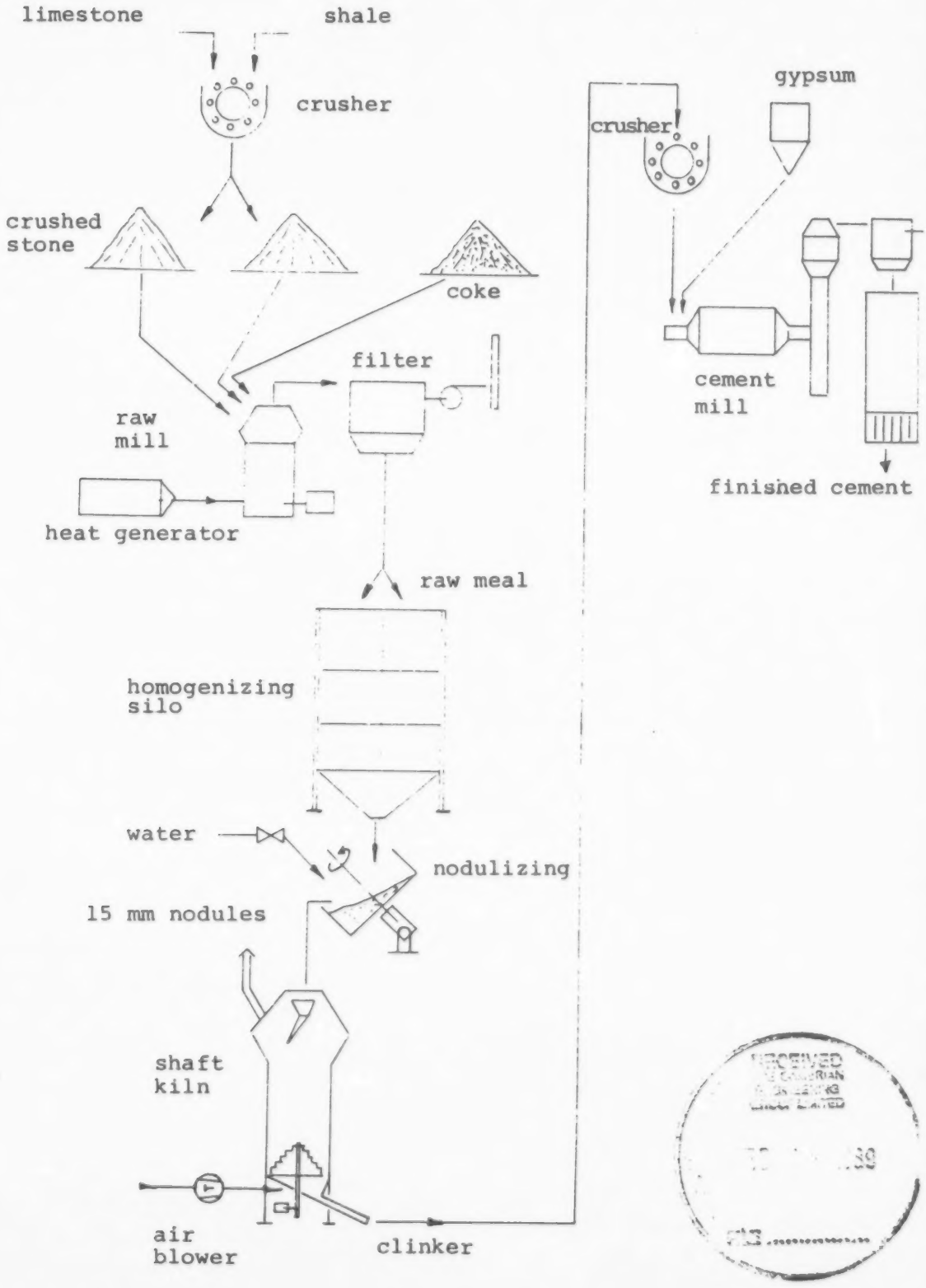


Costs of producing 1000 kg cement



sum = 100 % 168 %

Flow sheet of a cement plant with shaft kiln



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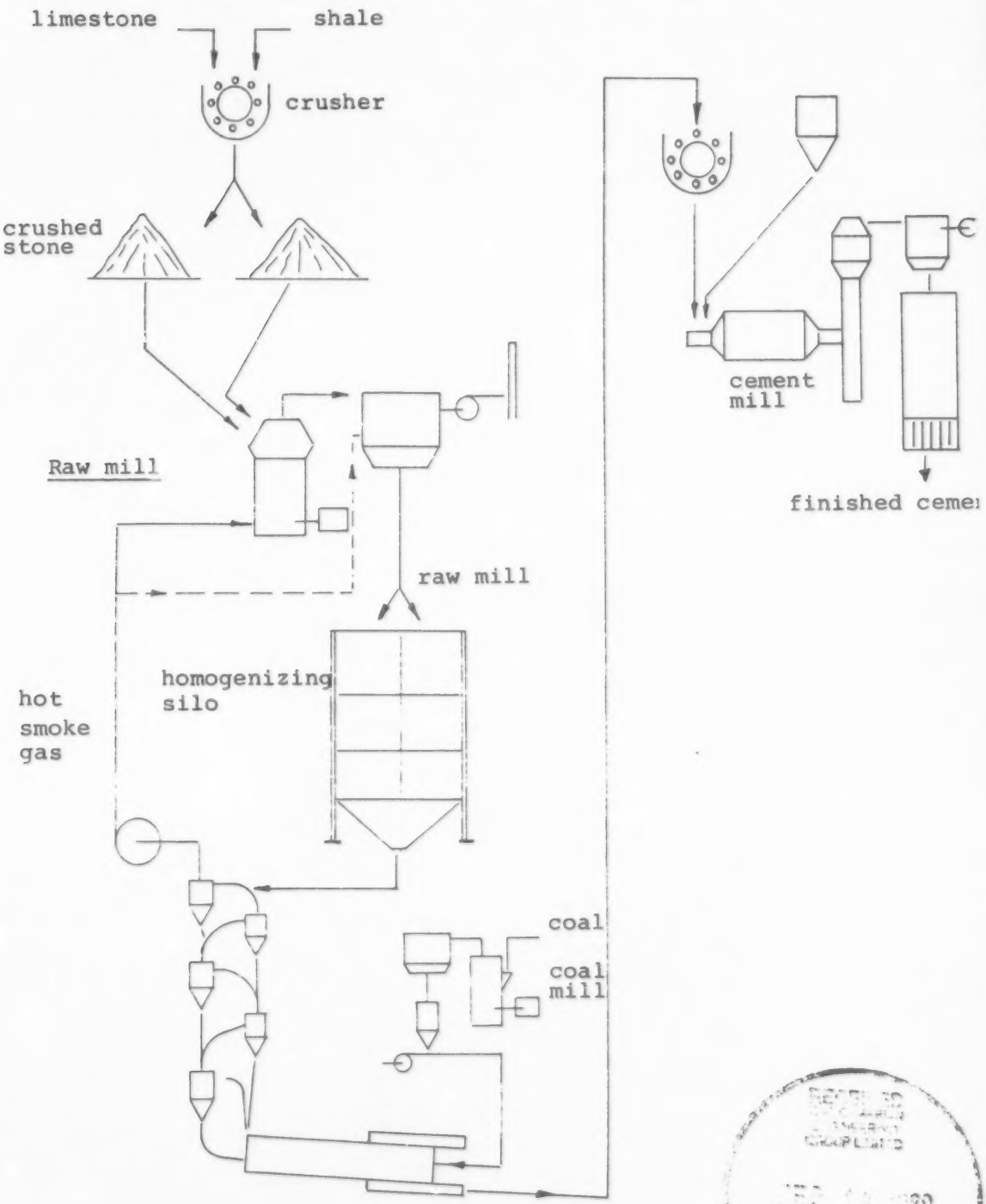
Conventional flow sheet of a cement plant



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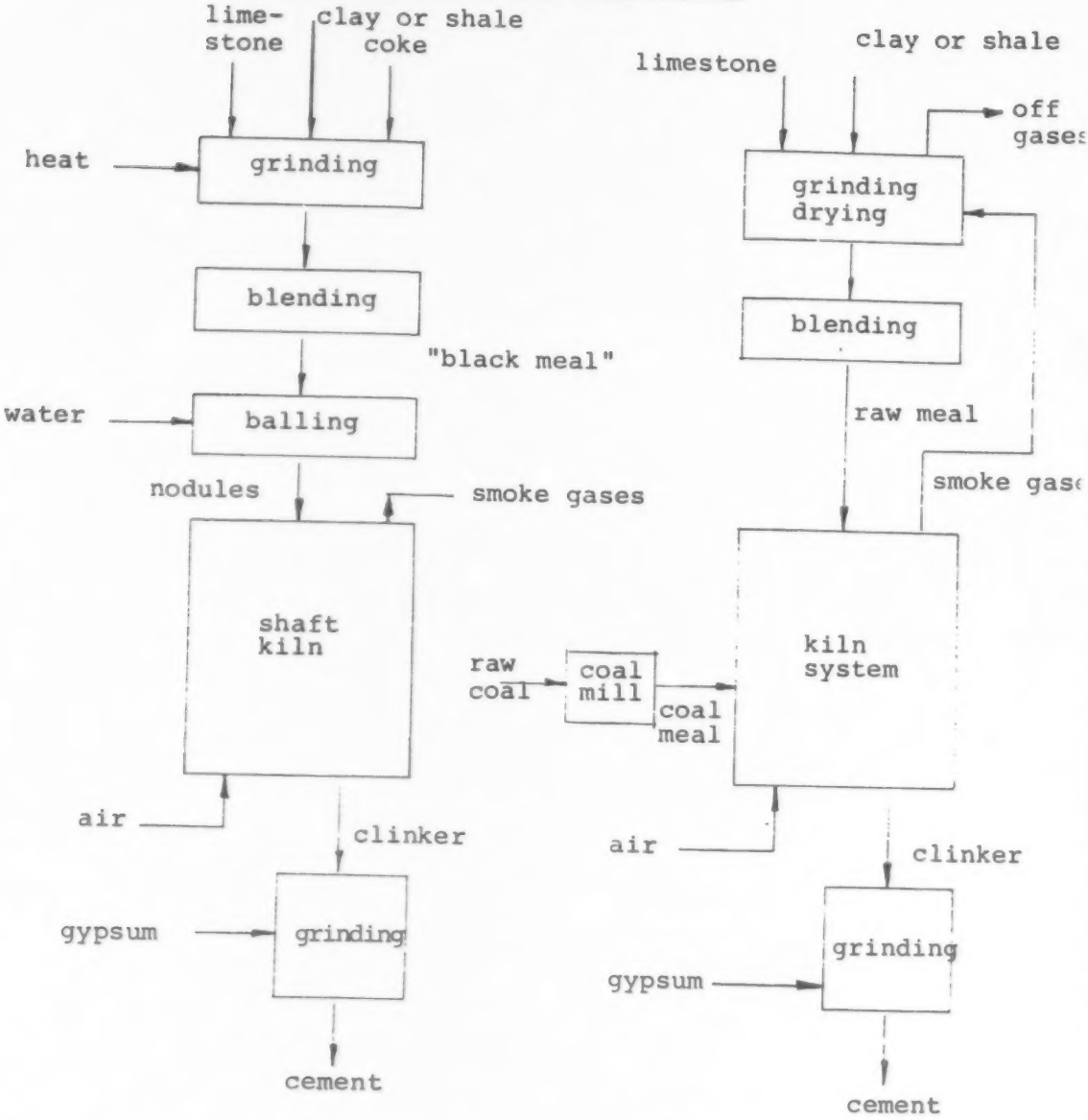
Basics of shaft kiln technology



Shaft kiln

Conventional dry process

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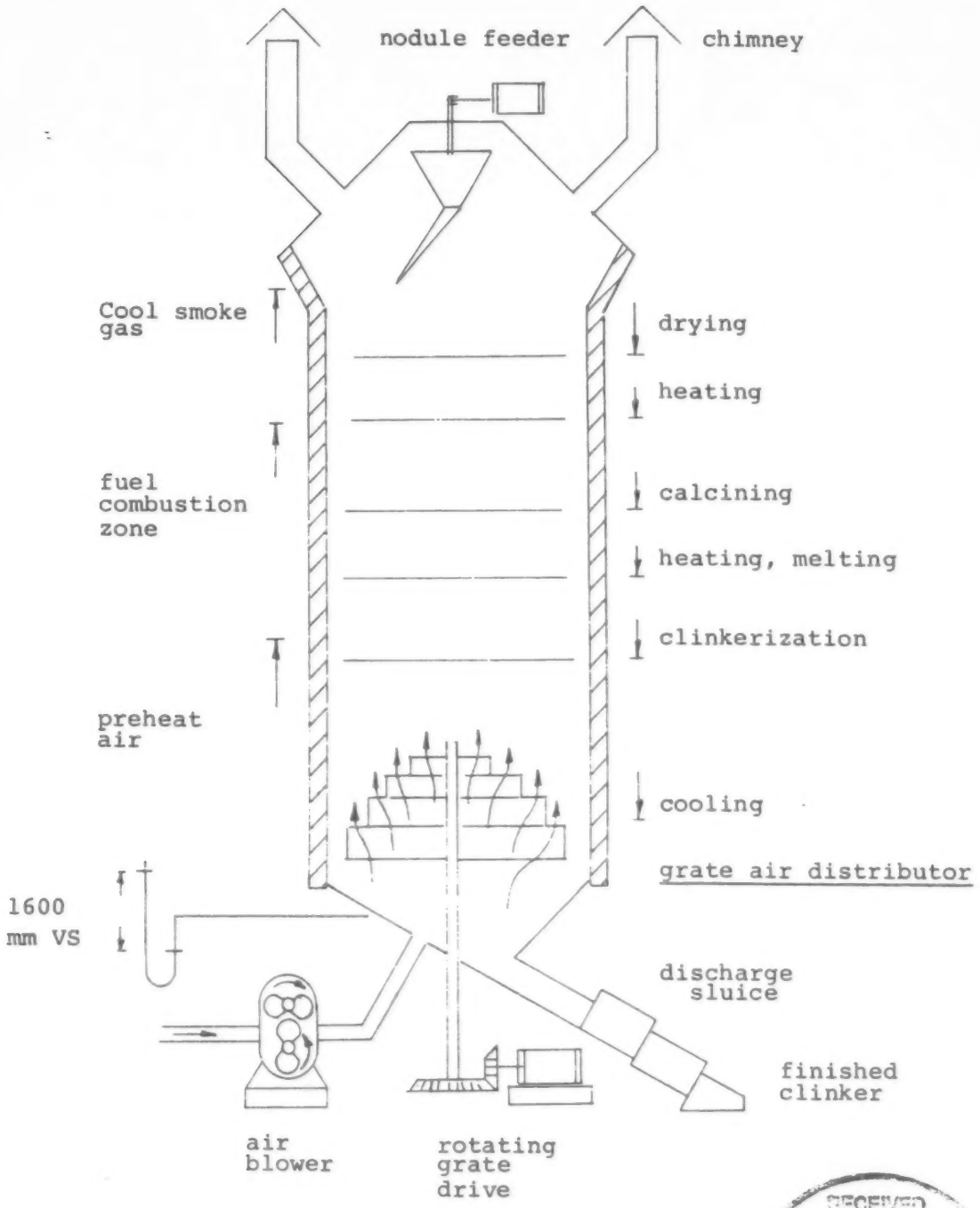
The shaft kiln



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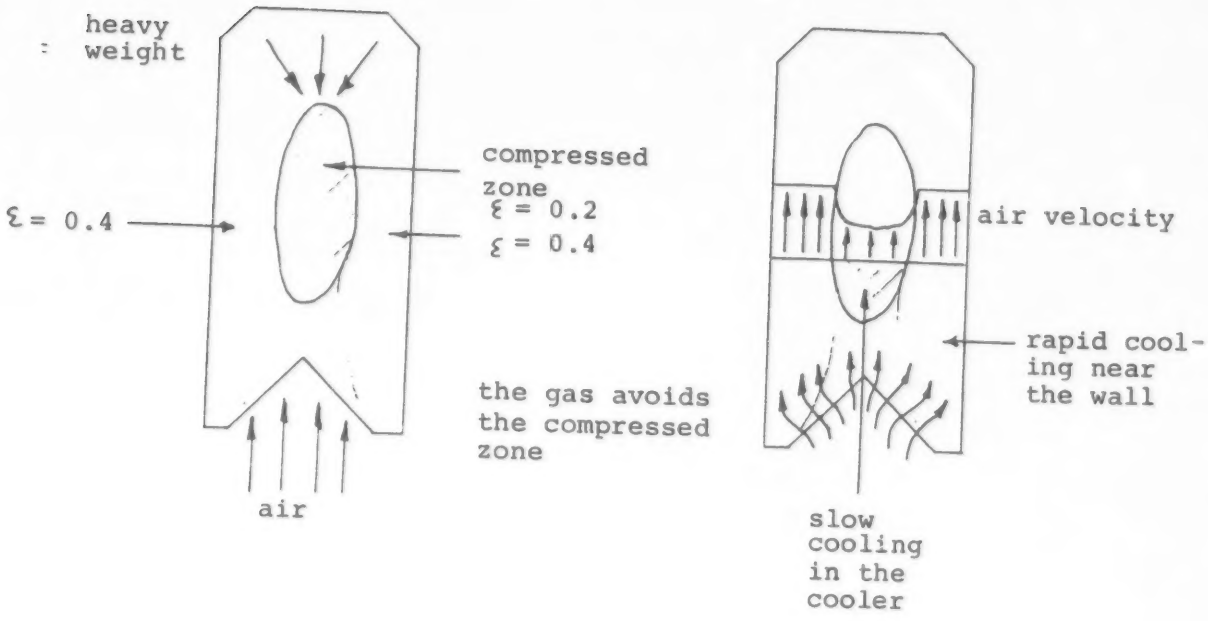
Clinker quality of shaft kilns



	Clinker produced in the centre	Clinker produced near the wall
porosity	low	high
cooling	slow	rapid
ox/red	reduced	oxidized
iron state	FeO, Fe	Fe_2O_3
C_3S condition	$C_3S \rightarrow C_2S + CaO$	C_3S retained
free CaO	yes	no
clinker quality	disastrous	OK

Thermal efficiency of a shaft kiln

Heat balance of a
180 tpd modern shaft kiln
Basis: 1 kg clinker

Theoretical heat consumption:	430 kcal/kg cl
Evaporation of water 1.6 kg dry nodules/kg cl 18% H_2O 585 kcal/kg H_2O:	168 kcal/kg cl
Smoke gas heat loss 1.33 kg flue gas + 0.6 kg CO_2 + 0.29 kg H_2O 120°C:	80 kcal/kg cl
CO loss 0.075 kg × 2415 $\frac{\text{kcal}}{\text{kg CO}}$	181 kcal/kg cl
Clinker heat loss 80°C	16 kcal/kg cl
Combustibles in clinker 0.2% C × 7838 kcal/kg C	16 kcal/kg cl
Radiation and convection	10 kcal/kg cl
Total	901 kcal/kg cl
Modern 5-stage preheater rotary kiln consumes	735 kcal/kg cl

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Comparison Table

	Shaft kiln	Rotary kiln with preheater
Mills	Raw mill Cement mill	Raw mill Coal mill Cement mill
Fuel	Coke, charcoal, anthracite	Coal, gas, oil
Required fineness Raw meal	8% > 90 my	15% > 90 my
Blending	Required	Required
Moisture	Add water in balling unit	Dry the raw materials in the raw mill
Kiln tph/m^3 Economy kcal/tph Power kWh/ton	High 900 6	Low 735 6
Smoke gas	5% CO 120°C moist	< 0,01% CO 350°C dry
Operational troubles	Compressed zone build up	Ash rings, cyclone pluggings
Clinker quality	Clinker must be sorted carefully	Uniform, very little is waste
Investments USD/tpd	Low	High

Das moderne Schachtofenwerk Semen Kupang auf der Insel Timor/Indonesien

Semen Kupang, a modern shaft kiln cement works in the island of Timor, Indonesia

Le four vertical moderne de Semen Kupang sur l'île de Timor en Indonesie

Von **E. G. Loesche** und **G. Frommelt**, Düsseldorf

Zusammenfassung

Auf der indonesischen Insel Timor wurde ein Schachtofenzementwerk mit 120000 t Jahresleistung errichtet, nachdem die Rentabilität eines Werkes dieser Größe und die Zweckmäßigkeit von Schachtöfen auf der Basis eines heimischen Kohlevorkommens geprüft worden war. Das Werk wurde in Kompaktbauweise ausgeführt, d.h. alle Betriebsanlagen sind im Zentrum des Werkes und die Vorrats- und Lagerhaltung um dieses herum angeordnet. Der Beitrag beschreibt Rohstoffe, Aufbau und Verfahrenstechnik, elektrische Einrichtungen und Inbetriebnahme im Dezember 1983. Alle Garantiewerte wurden günstig überschritten.

Summary

(Complete English translation in ZKG 2 1985 Editin B)

In the Indonesian island of Timor a shaft kiln cement works of 120000 t/ year capacity has been built. Before its construction a profitability analysis for a plant of this size was carried out and the suitability of shaft kilns for operation with indigenously mined coal was investigated. The cement works is designed on the compact principle, i.e., all the processing installations are located at the centre of the works, with the storage and stockpiling facilities disposed around them. The article describes the raw materials, constructional and process engineering features, electrical equipment, and commissioning of the works in December 1983. All the guaranteed values were amply attained.

Résumé

Sur l'île indonésienne de Timor a été construite une cimenterie avec four vertical d'une capacite annuelle de 120000 tonnes, après que la rentabilité d'une usine de cette dimension et l'adéquation des fours verticaux à un gisement local de charbon ont été vérifiées. L'usine a été édifiée en disposition compacte, c'est-à-dire que toutes les installations de fabrication sont au centre de l'usine et les aires d'approvisionnement et de stockage sont situées tout autour. Cet article donne une description des matières premières utilisées, de la technique de construction et de fabrication, des installations électriques et de la mise à feu en décembre 1983. Toutes grandeurs garanties ont été positivement dépassées.

1. Einleitung

Die Insel Timor liegt 1500 km östlich von der indonesischen Hauptstadt Jakarta entfernt. Die Ausdehnung der Insel in ihrer Länge beträgt 500 km, in der Breite 200 km. Die Bevölkerung Timors beläuft sich auf etwa zwei Millionen Menschen. Die politische und wirtschaftliche Entwicklung Timors verlief etwas unterschiedlich zu der der Hauptinseln. Es ist ein Anliegen der Zentralregierung, die östlichen Inseln wirtschaftlich zu entwickeln, was insbesondere für Timor gilt.

Die Firma Loesche, Düsseldorf erhielt deshalb den Auftrag zur Planung, Bau und Inbetriebnahme einer schlüsselfertigen Zementwerksanlage in der Nähe der im Westen der Insel gelegenen Hafenstadt Kupang. Zur Durchführung dieses Auftrages wurde ein Konsortium, bestehend aus Klöckner-Industrie-Anlagen (INA) und Indumation, Aarau, unter der Federführung von Loesche gegründet.

Die maschinelle und elektrische Einrichtung war zur Lieferung aus Europa vorgesehen. Der Stahlbau und die Bauausführung der Fundamente und Gebäude sowie die Montage

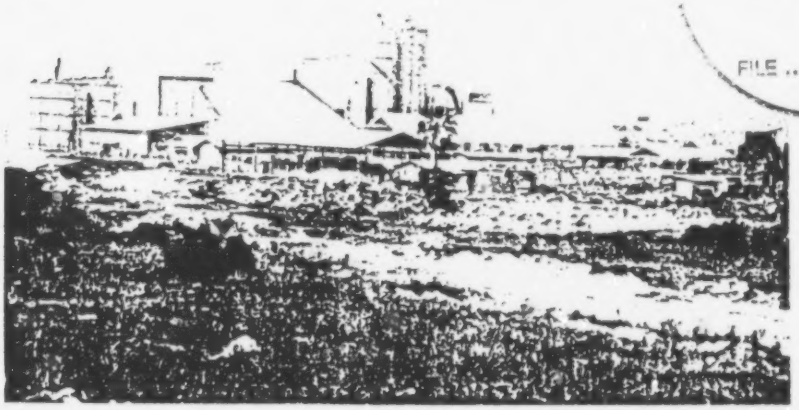


Bild 1: Gesamtansicht Zementwerk P. T. Semen Kupang, Indonesien

P. T. Semen Kupang cement works, Indonesia, general view

wurden an indonesische Firmen vergeben. Vorangegangen war eine sorgfältige und aufwendige Untersuchung der zwei entscheidenden Kernfragen:

1. Kann eine verhältnismäßig kleine Produktion, die den Bedarf der Insel und deren Umfeld deckt, überhaupt rentabel sein?

2. Ist der Schachtofen unter den Voraussetzungen der lokalen Verhältnisse die geeignete Produktionsform zur Klinkererzeugung, und hat er außer möglichen preislichen auch verfahrenstechnische Vorteile gegenüber der ebenfalls untersuchten Alternative eines Drehofens?

An der Untersuchung waren außer dem Konsortium der Besteller und Betreiber P.T. Semen Kupang sowie die Aktieninhaber P.T. Semen Gresik, die Bank Pembanguman, Indonesien, sowie die zuständigen Behörden beteiligt. Nachdem zuvor ein Schachtofen-Projekt für eine Jahresproduktion von 60000 t Zement untersucht worden war, wurde klar, daß die Kapazität unter den vorliegenden Umständen größer sein müsse. Eine Rentabilität errechnete sich erst bei der doppelten Produktion, also bei 120000 t/Jahr, für die zwei Schachtöfen vorgesehen wurden.

Im Vertrag war garantiert worden, im Dezember 1983 betriebsbereit zu sein. Das Gesamtinvestitionsvorhaben betrug ca. DM 75 Mio. Der Zeitplan für die Projektierung, Lieferung, Montage und Inbetriebnahme wurde exakt eingehalten und das Werk Mitte Dezember 1983 fertiggestellt und in Betrieb genommen (Bild 1).

2. Rohmaterialien

Um die Versorgung der Fabrik mit Rohmaterialien zu sichern, erhielt das Konsortium den Auftrag, geologische Gutachten für das Kalkstein- und Tonvorkommen zu erstellen. Geeigneter Kalkstein wurde in unmittelbarer Nähe der Fabrik in praktisch unbegrenzter Menge gefunden. Vorgesehen ist, den Kalkstein zu sprengen, mit Schaufelladern auf Kipper zu laden und zur Vorzerkleinerung zu transportieren. Die Tonlagerstätte liegt ca. 3,5 km südostlich der Fabrik. Da das Tonvorkommen heterogen ist, sind besondere Abbaumethoden vorgeschlagen worden. Die klimatischen Bedingungen auf der Insel Timor, wo etwa 350 mm Niederschlag je Monat von November bis März fallen, ließen Schwierigkeiten für die Rohstoffgewinnung und Aufbereitung erwarten.

Zur Korrektur der Rohmaterialmischung wurden Dosiermöglichkeiten für die Komponenten Kieselsäure und Eisenoxid vorgesehen.

Besondere Aufmerksamkeit galt dem Brennstoff. Hier ging es um zwei Entscheidungskriterien:

1. Gibt es in Indonesien Kohle oder Anthrazit, die für das Schachtofenverfahren geeignet sind?

2. Liegen die Vorkommen geeigneter Brennstoffe transportmäßig so günstig, daß der Brennstoff zu einem optimalen Preis beim Werk angeliefert werden kann?

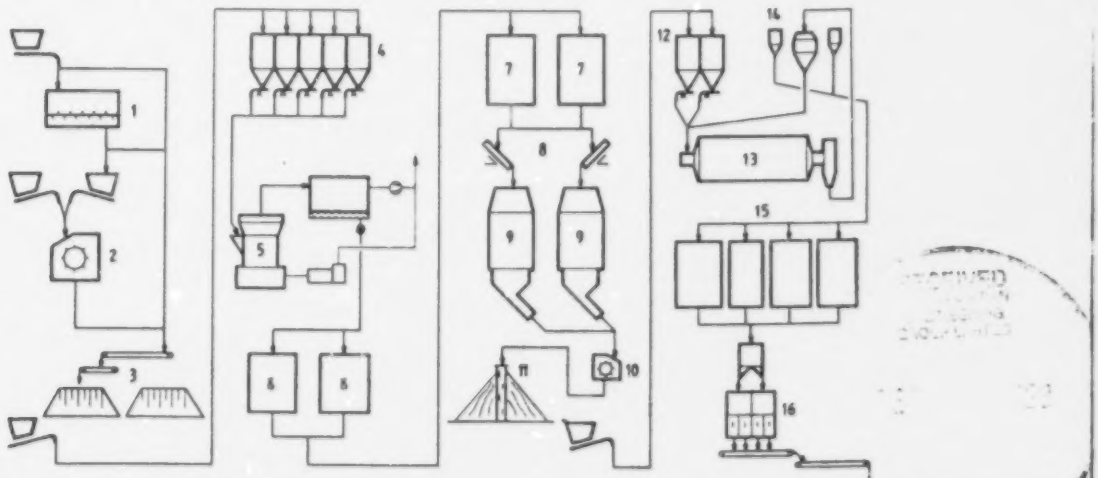
Die Antwort war in beiden Fällen positiv. Indonesien verfügt in Buckit Asam über eigene Kohlevorkommen, die einen ausgezeichneten Schachtofenbrennstoff darstellen.

Es gibt Kohle mit hoher Reaktivität, die damit für den Schachtofenprozeß besonders gut geeignet ist. Der Gehalt an flüchtigen Bestandteilen dieser Kohle ist verhältnismäßig hoch. Nach sorgfältigen Brenntests konnten für diese Kohle verbindliche Zusagen zur Brauchbarkeit gegeben werden. Der Antransport der Kohle per Schiff über die bestehende Hafenanlage und der Weitertransport per Lkw zur Fabrik konnten als gesichert angesehen werden.

3. Anlagenkonzept

Schachtofenwerke in der Dimension von Semen Kupang werden von Loesche als „Kleinzementwerke" projektiert. Es soll mit diesem Ausdruck einerseits der Unterschied zu Mini-Zementwerken deutlich gemacht werden, deren Kapazität unter 60000 t/Jahr liegt. Zum anderen soll zum Ausdruck gebracht werden, daß insbesondere durch den Schachtofen eine kompakte Bauweise der Fabrik ermöglicht wird.

In Kupang sind alle Produktionseinheiten, wie das Fließbild und der Grundriß zeigen (Bild 2 und 3), in unmittelbarer Nähe zueinander angeordnet. Bei der Dimensionierung der Materiallager sind die Forderungen des Kunden hinsichtlich der Lagerkapazität berücksichtigt worden. Außerdem wurde den Rohmaterial- und klimatischen Verhältnissen

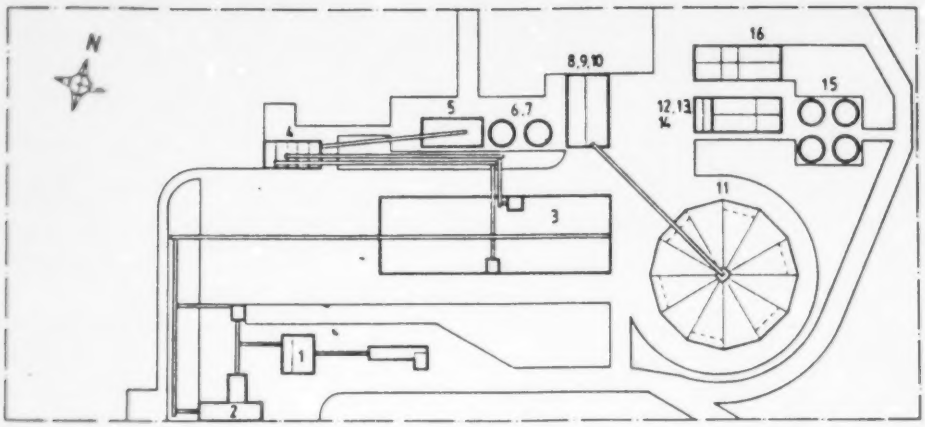


1 Trockner
2 Brecher
3 Mischbett
4 Vorbunker
5 Rohmühle
6 Homo-Silo
7 Rohmehl-Silo
8 Granulierteller
9 Schachtofen
10 Brecher
11 Klinkerlager
12 Vorbunker
13 Zementmühle
14 Sichter
15 Zementsilo
16 Packerei

1 Dryer
2 Crusher
3 Preblending and storage
4 Intermediate storage
5 Raw mill
6 Homogenizing
7 Raw meal silo
8 Pelletization
9 Vertical kiln
10 Crusher
11 Clinker storage
12 Intermediate storage
13 Cement mill
14 Classifier
15 Cement silo
16 Packing

Bild 2: Fließbild

Flow diagram



1 Trockner
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Bild 3: Grundriß

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2 Crusher
3 Pre-blending and storage
4 Intermediate storage
5 Raw mill
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7 Raw meal silo
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9 Vertical kiln
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11 Clinker storage
12 Intermediate storage
13 Cement mill
14 Classifier
15 Cement silo
16 Packing

Layout of the works

Rechnung getragen. Dieses für Schachtofenwerke neue Konzept wurde auch bei einem Projekt gleicher Größe für Madagaskar, im Werk Ciment d'Antsirabe, verwirklicht.

4. Aufbau der Anlage

4.1 Aufbereitung

Kalkstein und Ton werden gemeinsam in einem Hammerbrecher zerkleinert und über Gummigurtförderer zu dem Mischbett transportiert, welches nach dem Windrow-Verfahren aufgehaldet wird. Hochprozentiger Kalkstein als Korrekturkomponente wird mittels der gleichen maschinellen Einrichtung gebrochen und aufgehaldet. Dieses System hat sich während der Inbetriebnahme auch bei hohen Feuchtigkeiten bewährt. Während der Regenzeit kann der Ton in einem Schnelltrockner vorgetrocknet werden. Damit besteht eine zusätzliche Möglichkeit, Schwierigkeiten durch Verstopfung auf dem Weg bis zur Rohmühle zu vermeiden. Der Trockner ist so ausgelegt, daß auch Kohle oder Zuschlagstoffe vorgetrocknet werden können, wenn bei der Dosierung durch hohe Feuchtigkeiten Betriebsstörungen zu erwarten sind. Die einzelnen Komponenten können über das gleiche Transportsystem zur Lagerhalle befördert werden.

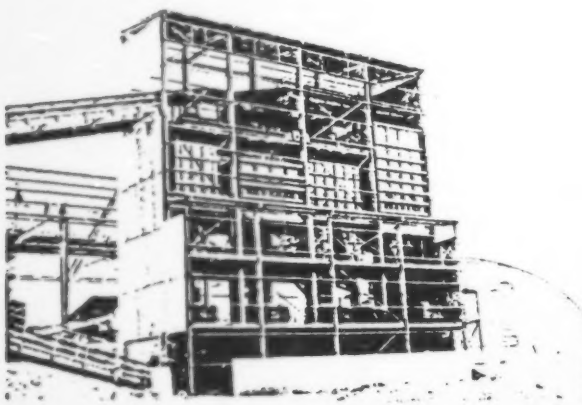

Bild 4: Dosierbunker
Feed hoppers

Vom Mischbett wird die Kalkstein-Ton-Mischung mittels Radlader entnommen und über ein Transportsystem in den Dosierbunker transportiert (Bild 4). Für die übrigen Zuschlagstoffe und die Kohle ist ein zweites Transportsystem vorhanden. Die Entnahme erfolgt mit dem gleichen Radlader.

4.2 Rohmehlerzeugung, Homogenisierung und Lagerung

Das Dosierverfahren arbeitet in der für Schachtofenwerke üblichen Weise: Aus dem Dosierbunker werden die Komponenten mittels Bandwaagen abgezogen und verwogen; nach Zusammenstellung der Rohmaterialmischung wird die erforderliche Brennstoffmenge zugewogen.

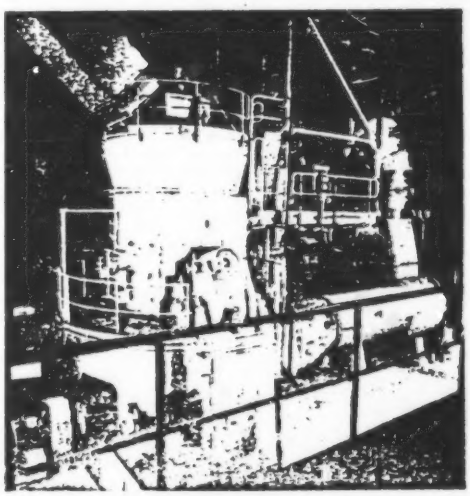

Bild 5: Loesche-Wälzmühle LM 21.20 zur Rohmehlerzeugung
Loesche LM 21.20 roller mill for raw meal production

Die Rohmaterialmühle, eine Loesche-Wälzmühle der Type LM 21.20 (Bild 5), ist für den Rohmehlbedarf des Werkes gut dimensioniert, und zwar, um einerseits über die Auslegungsdaten hinausgehende Feuchtigkeiten im Aufgabegut, die durch extreme Regenfälle hervorgerufen sein können,

zu trocknen. Zum anderen sollte auch die Möglichkeit bestehen, die Rohmehl-Kohle-Mischung feiner als vorgesehen zu vermahlen, falls zu einem späteren Zeitpunkt Brennstoffe, die aus Kostengründen verarbeitet werden sollen, dies erforderlich machen. Während der Inbetriebnahme hat die Mühle die vorgesehene Leistung auch bei Feuchtigkeiten von 17 % in der Rohmaterialmischung erreicht. Die Rohmaterialmühle wird von einem ölbefeuerten Heißgaserzeuger der Type Loma mit Heißgas versorgt.

Das Rohmehl gelangt mittels Becherwerk in eines der beiden Homogenisierungssilos, die auf den Vorratssilos angeordnet sind. Das Batch-System erlaubt Korrekturen, für die auch eine mögliche Rückführung aus den Vorratssilos in die Homogenisierungssilos vorgesehen ist.

4.3 Klinkerproduktion

Von den Vorratssilos wird das Rohmehl über ein Becherwerk auf die oberhalb der Ofenbühne liegende Dosierplattform transportiert. Ein Transportsystem zur Entlüftung des Ofenmehls sorgt für gleichmäßige Dosierung zu den Granuliertellern. Jeder Ofen ist mit einem Granulierteller ausgerüstet, von dem aus die Granalien über eine Drehschurre auf den Ofenquerschnitt verteilt werden. Jeder der beiden Schachtofen hat einen Durchmesser von 2,75 m und ist 9 m hoch. Die garantierte Tagesleistung eines Ofens von 175 t ließ sich ohne Schwierigkeiten bei guter Klinkerqualität erreichen. Während der Testläufe wurde auch die ausgelegte Leistung von 200 t/Tag nachgewiesen (Bild 6). Nach Verlassen des Ofens wird der Klinker in einem Backenbrecher auf die für den optimalen Betrieb der Zementmühle erforderliche Körnung vorzerkleinert.

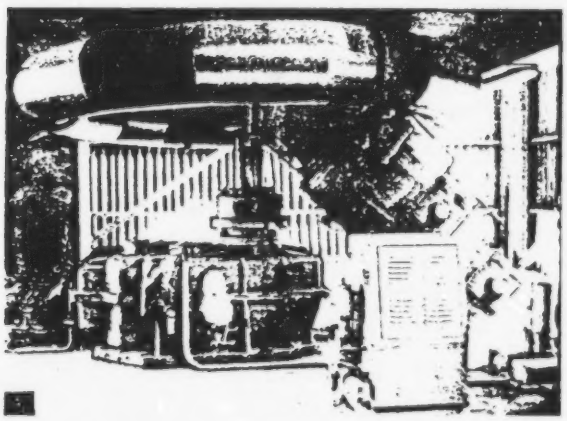

Bild 6: Schachtofenantrieb und -entleerung
Shaft kiln drive and emptying system

4.4 Klinkerlagerung und -vermahlung

Mit einem Stahlzellenband wird der Klinker zum Klinkerlager transportiert und von oben in einen Turm, der mit Auslaßklappen ausgerüstet ist, abgeworfen. Das überdachte Lager faßt 8000 m³ und wird von Radladern abgetragen (Bild 7). Über ein gemeinsames Transportsystem werden die Dosierbunker für Klinker und Gips gefüllt.

Die Zementmühle wird mittels Bandwaagen beschickt. Es wurde eine Rohrmühle mit 2,8 m Durchmesser x 9,6 m lang mit Becherwerkumlauf und Windsichter installiert. Die Mühle hat einen Antriebsmotor von 1000 kW. Die installierte Leistung mit allen zusätzlichen Aggregaten zusammen beträgt 1300 kW. Es besteht die Möglichkeit, die Anlage für die Vermahlung von Zement mit Puzzolan als Zuschlagstoff nachzurüsten.

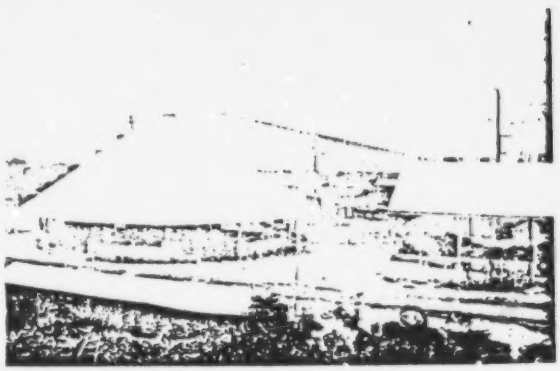

Bild 7: Klinkerlager
Clinker store

4.5 Zementvorratssilos, Packerei und Verpackung

Gebaut wurden vier Zementsilos mit je 950 m³ Inhalt. Damit besteht die Möglichkeit, verschiedene Qualitäten zu produzieren und je nach Bedarf auf Vorrat zu halten. Zur Zeit wird die gesamte Produktion in 40-Kilo-Säcke verpackt und mit Lkw zum Versand gebracht, da die Möglichkeiten für lose Verladung auf der Insel Timor noch nicht organisiert sind.

Die Packerei ist mit einer 4-Stutzen-Maschine ausgerüstet, die so ausgeführt wurde, daß die Bedienung durch zwei Packer erfolgen kann. Es ist möglich, ca. 1000 Säcke pro Stunde zu packen. Die Verladung erfolgt mittels Beladeband, welches entsprechend den lokalen Gepflogenheiten für Heckbeladung eingerichtet ist. Lose Verladung und Palettierung sind zunächst nicht vorgesehen. Es wurde aber die Möglichkeit geschaffen, die Anlage entsprechend nachzurüsten.

4.6 Elektrische Einrichtung

Die Versorgung der Fabrik erfolgt aus dem öffentlichen 20-kV-Netz. In einer Trafo-Station wird auf die Betriebsspannung für die einzelnen Verbraucher transformiert. Die drei großten Motoren der Anlage sind die Antriebsmotoren für die Rohmühle, für das Mühlengebläse der Rohmühle und für die Zementmühle. Die installierten Leistungen betragen 400 kW 400 kW und 1000 kW. Diese Motoren wurden als Hochspannungsmotoren mit einer Betriebsspannung von 6 kV gebaut. Alle übrigen Verbraucher sind für eine Betriebsspannung von 380 V vorgesehen. Ein getrenntes Netz ist für die Beleuchtung und die Versorgung mit Kraftstrom zur Durchführung von Reparaturen installiert worden.

Auf den Bau einer Zentralwarte wurde verzichtet. Die Schaltschranke mit Blindschaltbild und Meß- und Regeleinrichtungen wurden für die einzelnen Anlagenbereiche vorgesehen. Diese Schaltschranke sind so in die Anlage integriert, daß der zuständige Schichtführer von diesem Schrank aus die Anlage bedienen kann und gleichzeitig in die Lage versetzt wird, die Maschinen zu beobachten.

4.7 Labor und Verwaltungsgebäude

Besondere Sorgfalt galt der Ausrüstung des Labors, da alle zur Qualitätskontrolle erforderlichen Untersuchungen im Werkslabor durchgeführt werden müssen. Zur Unterbringung des Labors wurde vom Kunden ein architektonisch ansprechender, funktioneller und organisatorisch entsprechender Bau errichtet, in dem auch die Verwaltung und Betriebsorganisation untergebracht sind.

C-27

5. Trainingsprogramm

Die deutsche Baustellenleitung, die Fachmonteure und Inbetriebnahme-Ingenieure waren während der Montage- und Inbetriebnahmephasen in der Lage, der indonesischen Werksleitung und den Schichtführern der Betriebsabteilungen die maschinellen und elektrischen Einrichtungen und Funktionen zu erklären und sie mit der Bedienung und Wartung vertraut zu machen. Da klar war, daß sich die mechanischen Funktionen durch sorgfältige Einweisung an Ort und Stelle erklären lassen würden, wurde ein Trainingsprogramm in erster Linie nur für den Chemiker, seine Assistenten und für die Ofenbrenner erforderlich.

Während eines viermonatigen Programms wurden in Spanien und Österreich in Werken, die Loesche ausgerüstet hatte und die mit Schachtöfen im Schwarzmehlverfahren arbeiten, ein Training absolviert, das trotz anfänglicher Sprachschwierigkeiten in jeder Hinsicht erfolgreich war und die erhofften Resultate zeigte. So stand bei Inbetriebnahme ein Kern von tüchtigen, gut informierten und einsatzfreudigen indonesischen Mitarbeitern zur Verfügung.

6. Inbetriebnahme

Mit großem Interesse hatte man von indonesischer Seite die Inbetriebnahme erwartet. Nicht nur kundenseitig, die Fabrik gehört mehrheitlich dem staatlichen Zementkonzern Semen Gresik, sondern auch seitens der zuständigen Behörde in der Regierung, von der die Entscheidung zugunsten eines Schachtofenzementwerks ausgegangen war. Um so mehr war man nun gespannt, ob diese Entscheidung richtig war und ob der im Schachtofen erzeugte Zement wirklich qualitativ ebenbürtig und kostenmäßig günstig hergestellt werden könne.

TABELLE 1
Garantie- und Testwerte
Guaranteed values and values attained in the tests

	Dim.	Garantie	erreicht
Rohmühle			
Fertiggutproduktion	t/h	30	49
Feinheit % R. DIN 0.09 mm	%	8–15	10–12
Aufgabefeuchte	%	14	6.6*) (vorhanden)
Restfeuchte	%	< 1	0.5
Start am 29. 5. 1984 Ende am 2. 6. 1984			
Ofenanlage			
Klinkerproduktion während 24-Std.-Betrieb	t	350	357
Spezifischer Wärmeverbrauch	kcal/kg Kli.	980	875
Gesamtproduktion während des 5-Tage-Tests	t	1750	1786
Zementmühle			
Produktion an Zement ASTM Type I	t/h	25	25.83
spez. Oberfl. n. Blaine	cm^2/g	3200	3545
Gesamtproduktion während des 5-Tage-Tests	t	1820	2003
Spezifischer Arbeitsbedarf für – Rohmehlmahlanlage – Ofenanlage – Zementmahlanlage gesamt	kWh/t	85.5	82.90
Start am 29. 5. 1984 Ende am 2. 6. 1984			

*) Während der Regenzeit in den Monaten Januar bis März wurde die Mahlanlage wochenlang mit Feuchtigkeit zwischen 14 % und 17 % betrieben und hat dabei durchschnittlich 38 t/h Rohmehl erzeugt.

Es mußte deshalb von Loesche, als dem für die Inbetriebnahme verantwortlichen Unternehmen, alles daran gesetzt werden, daß der Zement vom Start weg qualitativ hochwertig war. Im Steinbruch traten Schwierigkeiten auf, die vom Betreiber zu vertreten waren. Es fehlte die Genehmigung zum Sprengen. Deshalb konnte nur Oberflächenmaterial durch Rippen gewonnen werden. Trotzdem war es möglich, ein Brennstoffrohmaterialgemisch, das Schwarzmehl, zu produzieren, welches für die Inbetriebnahme ausgezeichnete Ergebnisse erwarten ließ. Der erste Ofen ging am 15. Dezember 1983 in Betrieb, der zweite wurde eine Woche später gezündet. Der gesamte Zement entsprach von Anfang an der Norm und konnte verkauft werden.

Die Abnahmeläufe wurden zwischen dem 1.5. und 2.6.1984 durchgeführt. An fünf hintereinander folgenden Tagen sollte die garantierte Leistung der Anlage und der spezifische Verbrauch von elektrischer und Wärmeenergie nachgewiesen werden. Die erreichten Werte sind in Tabelle 1 aufgeführt.

Die Produktion wurde von Anfang an von indonesischem Personal geleitet. Nach Optimierung und Abnahme wurde das deutsche Personal schrittweise abgezogen.

Bild 8: Staatspräsident Soeharto bei der Einweihungsfeier
President Soeharto of Indonesia at the inaugural ceremony

Am 14. April 1984 kam Staatspräsident Soeharto (Bild 8) auf die Insel Timor nach Kupang. Bei der Einweihungsfeier wies er vor mehreren hundert Gästen und im Fernsehen auf die politische Bedeutung des Werkes für die Entwicklung der Infrastruktur der Insel hin.

Über die politische Zweckmäßigkeit hinaus muß eine solche Anlage natürlich in erster Linie rentabel sein. Für eine Fabrik mit einer so geringen Kapazität von 120000 t/a ist das nur unter ganz bestimmten Voraussetzungen möglich. Die Fabrik muß von der nächsten zentralen Produktionsstätte so weit entfernt sein, daß die Transportkosten für den Zement die Differenz zu den Produktionskosten zwischen der kleinen und der großen Fabrik übersteigen.

Der ständige lokale Absatz muß gesichert sein, damit die Fabrik gut ausgelastet ist. Liegt diese Voraussetzung vor, so zeichnet sich eine Schachtofenzementfabrik gegenüber einem Drehofenwerk durch bessere Flexibilität und höhere Betriebssicherheit aus. Die insgesamt niedrigeren Investitionskosten, die in erste Linie auf die kompakte Ofenbauweise zurückzuführen sind, kommen der Rentabilität zugute.

Es ist bereits heute, neun Monate nach Inbetriebnahme, erkennbar, daß sich der Aufbau der Fabrik und die Produktion von Zement günstig auf die Entwicklung der Provinz auswirkt. Von dem Projekt geht eine Initialzündung aus, die sich auch auf andere Wirtschaftszweige übertragen hat.

the cambrian engineering group limited

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Mississauga, Ontario
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December 21, 1988

D35.10

Journal of Cement Research Progress
c/o American Ceramic Society
Cements Division
65 Ceramic Drive,
Columbus
Ohio

Gentlemen:

We are seeking information on the current state of the technology for manufacturing cement using vertical kilns. Our specific concerns include:

1. Can vertical kilns produce cement of a quality level to meet or exceed ASTM Standards.

2. If the cement product does not meet ASTM Standards can it be produced to meet some other uniform standard or manufacturer's quality assurance level.

3. What capacity range is practical for vertical kiln cement production.

4. Are there any institutions or manufacturers developing or marketing vertical kiln units in North America or Europe at the present time.

Your earliest response to this inquiry would be very much appreciated.

Yours very truly

THE CAMBRIAN ENGINEERING GROUP LIMITED

Gerry Shessel
Mechanical Design Engineer.

GS:tmcc

The Cambrian Engineering offices are in MISSISSAUGA SASKATOON OTTAWA

SOUTHWESTERN PORTLAND CEMENT COMPANY

P. O. BOX 937
VICTORVILLE, CALIFORNIA 92393-0633
(619) 245-1681

7 March 1989

Mr. Gerry Shessel
The Cambrian Engineering Group, Ltd.
2200 Argentia Road
Mississauga, Ontario L5N 2K7
CANADA

Dear Mr. Shessel:

I recently received your inquiry concerning cement manufacturing with vertical (shaft) kilns from the American Ceramic Society.

In answer to your questions, I am not aware of any vertical kilns presently being used in the U.S. or Canada for the manufacture of portland cement clinker. However, they are still used in Europe for the calcination of limestone. Certainly, cement clinker can be (and has been) made with such equipment. I don't know what the quality level would be compared to conventional rotary kiln clinker, but it could probably meet ASTM specifications. I would suspect that a major difficulty to be anticipated would be the production of reduced clinker.

I have enclosed a copy of PCA Manufacturing Process Dept. paper M-165, as well as several recent references to shaft kilns in Zement-Kalk-Gips. For further information, I would suggest that you contact the Portland Cement Association in Skokie, Illinois or one of the major manufacturers of pyroprocessing equipment -- the Fuller Company, Humboldt Wedag, Polysius Corp., and F. L. Smidth & Co.

Sincerely,

W. A. Klemm
Manager, Central Process Laboratory

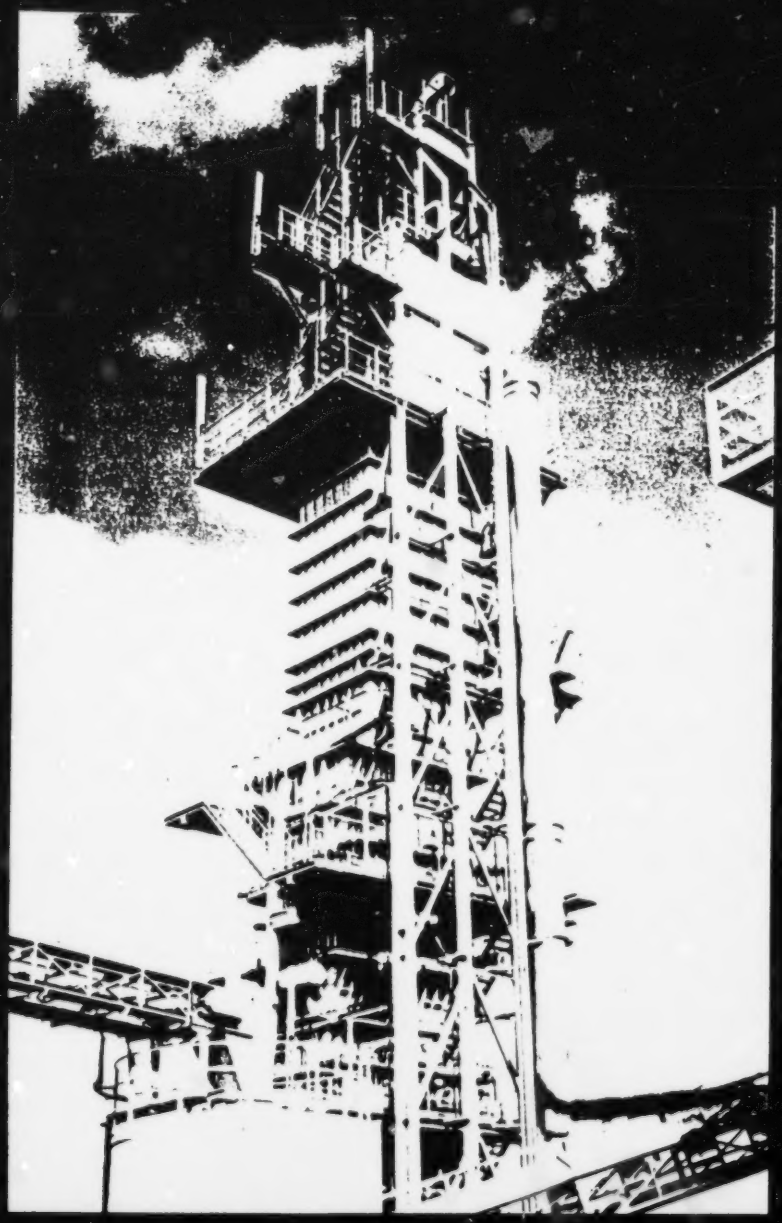
WAK:cl

Enclosures

ER IM ANLAGENBAU

YOUR PARTNER IN PLANT AND CONSTRUCTION

IAF
MEHRKAMMERSCHACHTÖFEN
MULTI-CHAMBER SHAFT KILN



IAF-MEHRKAMMERSCHACHTOFEN
zum Brennen von Kalk, Dolomit und Magnesit

MULTI-CHAMBER SHAFT KILN
for calcining of limestone, dolomite and magnesite

SPEZIFISCHE DATEN / SPECIFIC DATA

Leistung Capacity	40 – 400 t/Tag 40 – 400 t/day
Steinkörnung Grain size	15 – 150 mm
Wärmebedarf Heat consumption	3.980 kJ/kg
Elektrischer Energieverbrauch Consumption of electr. energy	≦ 18 kWh/t
Rest-CO_2-Gehalt Resid. CO_2 content	2 %

Brennstoffe: Kohlenstaub, Feinkohle, Schweröl, Erdgas, Mischgas, Karbidofengas, Convertergas, etc.

Fuels: Pulverized coal, fine coal, heavy fuel oil, natural gas, mixed gas, carbide furnace gas, converter gas, etc.

IAF
projektiert, liefert und errichtet weltweit Kalkschachtöfen und schlüsselfertige Kalkanlagen.

IAF
plans, supplies and erects worldwide shaft lime kilns and turnkey lime plants.

IAF

Industrieanlagen Auerbach Föro GmbH
Zechenstraße 5-9
D-4750 Unna
Telefon (02303) 671-0
Tx 8229260 wmg d

Brennstoffalternativen zum Koks bei konventionellen Schachtöfen *)

Alternatives to coke as fuel for conventional shaft kilns

Combustibles alternatifs au coke pour les fours droits traditionnels

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THE CAMBRIAN
GROUP LIMITED
MAR 15 1989
FILE .....

Von W. Höltje, Goslar

Zusammenfassung

Der in der deutschen Kalkindustrie erzeugte Branntkalk wird sowohl in der Erzeugungsmenge als auch in der Ofenbauart größtenteils noch immer in konventionellen Schachtöfen produziert. Die Entwicklung und die oft stark schwankenden Preise der Brennstoffe zwangen die Ofenbetreiber aus wirtschaftlichen Überlegungen statt des üblicherweise verwendeten Kokses auch andere Energiearten einzusetzen. Bei den festen Brennstoffen kommen hierbei Anthrazit, Braunkohlen-Hochtemperaturkoks und Petrolkoks zur Anwendung. Diese fast ausschließlich kleineren Körnungen haben eine Verlagerung der Brennzone zur Folge, verbunden mit höheren Temperaturen und Wärmeverbrauchszahlen. Neben diesen Brennstoffen werden Heizöl „S", Braunkohlenstaub und Gas eingesetzt. Auch die unterschiedlichen Alternativen für die Zuführung von Gas, Öl und Kohlenstaub führen zu erhöhtem Wärmeaufwand. Trotzdem sind diese Verfahren für die Kalkindustrie wichtig, weil nur ein geringer Investitionsaufwand notwendig ist, um die Öfen auf den jeweils preisgünstigsten Brennstoff umzustellen. Für die verschiedenen Lösungen ergeben sich Vor- und Nachteile hinsichtlich Entsäuerung, Reaktivität, Wärmeverbrauch, Brennstoffverteilung und Luftfaktoren.

Summary

(Complete English translation in ZKG 3/1989, Edition B)

Quicklime produced in the German lime industry is still burned largely in conventional shaft kilns, both in terms of quantity output and in the design of the kilns themselves. The trend in fuel prices and the often sharp price fluctuations have compelled kiln operators, for reasons of economy, to use other fuels besides the coke they normally employ. In the solid fuel range these alternatives are anthracite, lignite high-temperature coke and petroleum coke. These fuels, almost invariably composed of smaller particles than ordinary coke, cause a displacement of the burning zone, this being associated with higher temperatures and higher heat consumption figures. Besides these solid fuels, heavy fuel oil, pulverized lignite and gas are used. The various alternatives for firing with gas, oil and pulverized fuel likewise result in higher heat consumption. Nevertheless these methods are important for the lime industry because they entail only a low capital expenditure for converting the kilns to whatever happens to be the cheapest fuel. The various solutions are associated with advantages and disadvantages with regard to calcination, reactivity, heat consumption, fuel distribution and excess air factors.

Résumé

La chaux vive produite dans l'industrie allemande de la chaux est encore pour sa plus grande part dans des fours droits traditionnels, aussi bien en ce qui concerne la quantité de production que le type de construction du four. L'évolution et les prix souvent fortement fluctuants des combustibles contraignent les utilisateurs de four, pour des raisons économiques, à rechercher, au lieu du coke habituellement employé, d'autres types d'énergie. Parmi les combustibles solides viennent en considération l'anthracite, le coke à haute température de lignite et le coke de pétrole. Les granularités presqu'exclusivement fines ont pour résultat un déplacement de la zone de cuisson, lié à des températures et des indices de consommation thermique élevés. Outre ces combustibles sont utilisés du fuel „S", du lignite pulvérisé et du gaz. Les différentes possibilités d'alimentation en gaz, en fuel et en charbon pulvérisé entraînent des dépenses d'énergie accrues. Ces procédés sont cependant importants pour l'industrie de la chaux car ne sont nécessaires que des investissements réduits pour convertir les fours au combustible économiquement le plus favorable. Pour chaque solution apparaissent des avantages et des désavantages quant à la décarbonatation, la réactivité, la consommation de chaleur, la distribution du combustible et les facteurs d'air.

1. Einleitung

Wenn man über Einsatzmöglichkeiten alternativer Brennstoffe für koksbeheizte Schachtöfen spricht, dann bezieht sich dieses auf Öfen, die – abgesehen von der Modernisierung der Beschickung und Austragung – schon vor Jahrzehnten betrieben wurden. Aufgrund des einfachen Aufbaus und der Wirtschaftlichkeit – gekennzeichnet durch niedrigen Wärme- und Stromverbrauch und geringen Futterverschleiß – sind diese Öfen aber noch immer interessant, sofern die erreichbaren Kalkqualitäten den Anforderungen der Kunden gerecht werden.

Laut der letzten Umfrage des Bundesverbandes der Deutschen Kalkindustrie im Jahre 1985 halten die konventionellen Schachtofen – wie aus dem Balkendiagramm (Bild 1) hervorgeht – sowohl bezüglich der Anzahl mit 53 % ≙ 67 Öfen als auch der Erzeugung mit 30 % noch immer die Spitzenposition unter allen Brennaggregaten.

Im Vordergrund standen in den letzten Jahren und Jahrzehnten jedoch vornehmlich die modernen Öfen, da man mit diesen eher in der Lage war, Öl, Gas oder Kohlenstaub und z.T. auch stückige Festbrennstoffe relativ problemlos einzusetzen und sich damit jeweils den preisgünstigsten Brennstoffen anzupassen. Dieses traf für die üblicherweise mit Koks befeuerten Schachtöfen nicht zu. Die Preisvorteile der flüssigen und gasförmigen Brennstoffe gegenüber Koks (Bild 2) zwangen bis 1979 und ab 1985/86 wieder die Betreiber von Koksofen – wollten sie mit dem Verkaufsprodukt konkurrenzfähig bleiben – sich Gedanken darüber zu machen, wie man den jeweils günstigsten Brennstoff auch in einem konventionellen Ofen einsetzen kann. Es bedurfte vieler Versuche, um zum Erfolg zu gelangen. Heute ist es möglich, in diesen Öfen neben stückigen Brennstoffen auch Öl, Gas und Kohlenstaub einzusetzen.

Als stückige Brennstoffe kommen zur Anwendung:

Koks:	Körnung 20–80 mm, gestuft
Anthrazit:	Körnung 2–18 mm, gestuft
Braunkohlenhoch-temperaturkoks:	0–5 mm, gestuft
Petrolkoks:	Körnung 15–25 mm,
als flüssige Brennstoffe:	Heizöl S,
als gasförmige Brennstoffe:	Erdgas und Butan,
als staubförmige Brennstoffe:	Braunkohlenstaub.

*) Vortrag zur 14. Technischen Tagung des Bundesverbandes der Deutschen Kalkindustrie e.V., Neuß (6. – 7. 10. 1988)

Einsatzmöglichkeiten des weiterentwickelten Mehrkammer-Schachtofens

Operational capabilities of the advanced multiple-chamber shaft kiln

Les possibilités d'utilisation du four droit à plusieurs chambres dont le développement a été poursuivi

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MAR 15 1989

Von **P. Zeisel**, Unna

Zusammenfassung

Der neue Mehrkammerschachtofen mit Brennräumen und Gegenstromkühlzone wird mit Erdgas, Schweröl, Kohlenstaub oder Feinkohle der Körnung von 0/1 mm befeuert und für Leistungen von 50 bis 225 t Kalk/d gebaut. Der Wärmebedarf beträgt bei einer Ofenleistung von 100 t Kalk/d, einem $CaCO_3$-Gehalt im Kalkstein von 97,1% und einem Rest-CO_2-Gehalt von 1% ca. 3968 kJ/kg Kalk. Der Ofen wird mit Steinkörnungen von 25/50, 30/90 oder 20/150 mm beschickt. Der Kraftbedarf beträgt bei Aufgabe der Körnung 20/150 mm ca. 20 kWh/t und bei 20/50 mm ca. 27 kWh/t Kalk. Sowohl hochprozentiger Kalkstein als auch Mergel-Kalk werden gebrannt. Der Brennstoff wird über 6 Brennräume mit je 2 Brennern zugeführt. Der Brenngrad des Kalkes wird über die Brennstoffverteilung beeinflußt. Durch Ändern der Brennstoff- und Luftverteilung kann im unteren Bereich der Brennzone auch reduzierende Atmosphäre eingestellt und unter bestimmten Bedingungen der Schwefelgehalt im Kalk verringert werden. Die Abgase werden mit Gewebefiltern entstaubt, denen ein Luftkühler vorgeschaltet ist. Bei Nutzung der Abgaswärme zur Mahltrocknung können dem Ofen ca. 189 kJ/kg Kalk gutgeschrieben werden. Der Ofen läuft vollautomatisch. Die Wartung beschränkt sich im wesentlichen auf den Schmierdienst.

Summary

(Complete English translation in ZKG 3/1989, Edition B)

The new multiple-chamber shaft kiln with combustion chambers and countercurrent cooling zone is fired with natural gas, heavy fuel oil, pulverized coal or small coal of 0–1 mm particle size and is built for capacities ranging from 50 to 225 t of lime per day. Heat consumption is about 3968 kJ/kg of lime for an output of 100 t/day, a $CaCO_3$ content of 97.1 per cent in the limestone and a residual CO_2 content of 1 per cent. The kiln is fed with stone particle size fractions of 25–50, 30–90 or 20–150 mm. Power consumption is about 20 kWh/t of lime for 20–150 mm and about 27 kWh/t for 20–50 mm feed size. High-grade limestone as well as marly limestone can be burned. The fuel is supplied to six combustion chambers, each with two burners. The degree of burning of the lime can be modified via the fuel distribution. By altering the fuel and air distribution it is possible to obtain a reducing atmosphere in the lower part of the burning zone and, under certain conditions, to cut down the sulphur content in the lime. The exit gases are dedusted with fabric filters preceded by an air cooler. If the exit gas heat is utilized for drying the material during grinding, the heat saving to the kiln can be put at about 189 kJ/kg of lime. Kiln operation is fully automatic, servicing being limited essentially to lubrication.

Résumé

Le nouveau four droit à plusieurs chambres de combustion et zone de refroidissement à contre-courant est chauffé au gaz naturel, au fuel lourd, au charbon pulvérisé ou à la houille fine d'une granularité de 0/1 mm et construit pour des rendements de 50 à 225 tonnes de chaux par jour. Le besoin en chaleur d'élève, pour un rendement du four de 100 tonnes de chaux par jour, une teneur en $CaCO_3$ du calcaire de 97,1% et une teneur résiduelle en CO_2 de 1%, environ 3.968 kJ par kilo de chaux. Le four est alimenté par une roche de 25/50, 30/90 ou 20/150 mm. Le besoin en énergie s'élève, pour une alimentation en morceaux de 20/150 mm à environ 20 kWt par tonne et de 20/50 m à environ 27 kWh par tonne de chaux. Le four peut brûler un calcaire de haut pourcentage aussi bien qu'un calcaire marneux. Le combustible est amené à 6 chambres de combustion munies chacune de deux brûleurs. Le degré de cuisson du calcaire est influencé par la distribution du combustible. En modifiant cette distribution, ainsi que celle de l'air, on peut créer une atmosphère réductrice dans le domaine inférieur de la zone de cuisson; on peut également dans certaines conditions réduire la teneur en soufre du calcaire. Les gaz d'échappement sont dépoussiérés avec des filtres-tissus qui sont précédés d'un refroidisseur à air. En cas d'utilisation de la chaleur des gaz d'échappement pour le broyage-séchage, le four peut économiser environ 189 kJ par kilo de chaux. Le four fonctionne d'une manière totalement automatique. L'entretien se limite essentiellement à des opérations de lubrification.

Einleitung

Unterschiedliche Rohmaterialien, steigende Ansprüche an den Branntkalk, multivalente Befeuerung mit gasförmigen, flüssigen und festen Brennstoffen und möglichst geringe Personal- und Betriebskosten machten die Weiterentwicklung des Mehrkammerschachtofens erforderlich, der heute für Durchsätze von 40 bis 225 t/d gebaut wird. Über den weiterentwickelten Ofen wurde bereits früher ausführlich berichtet[1], so daß Aufbau und Funktion als bekannt vorausgesetzt werden. Im folgenden werden die Einsatzmöglichkeiten dieses Mehrkammerschachtofens gezeigt.

Der neue Ofen unterscheidet sich von der früheren Konstruktion durch 2 wesentliche Merkmale:

- Brennräume anstelle von Brennkammern und
- Gegenstromkühlung mit Heißluftabsaugung statt Gleichstromkühlung.

Der Aufbau der Ofenanlage mit Butan- und Braunkohlenstaubfeuerung und Heißluftabsaugung wurde in der Veröffentlichung von D. Lewerentz und P. Zeisel[2] dargestellt. Die Brennräume haben gegenüber Brennkammern den Vorteil, daß sich das Brenngut durch den Brennraum bewegt und bei Kohlefeuerung die Brennstoffasche nach unten zum Ofenaustrag fördert und sich daher keine störenden Ascheansätze bilden können. Durch den Austausch der Gleichstrom- gegen eine Gegenstromkühlzone mit Heißluftabsaugung wurde nicht nur der Wärmebedarf erheblich gesenkt, sondern auch die zu entstaubende Abgasmenge auf ca. 1/3 des ursprünglichen Wertes verringert, so daß heute wesentlich kleinere Entstaubungen eingesetzt werden können. Die Energieeinsparung bei Gegenstromkühlung gegenüber Gleichstromkühlung beträgt unter sonst gleichen Bedingungen ca. 200 kcal/kg Kalk, was P. Zeisel bereits gezeigt hat[1].

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MANUFACTURING PROCESS DEPARTMENT
M-165

Forty Years of Shaft Kiln Development

by

DR. EBERHARD SPOHN

President, Heidelberg Cement Co.
Heidelberg, Germany

August, 1961

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Presented at Regional Fall Meeting

GENERAL TECHNICAL COMMITTEE

PORTLAND CEMENT ASSOCIATION

Sept. 19-22, 1960, Toronto, Canada

C-36

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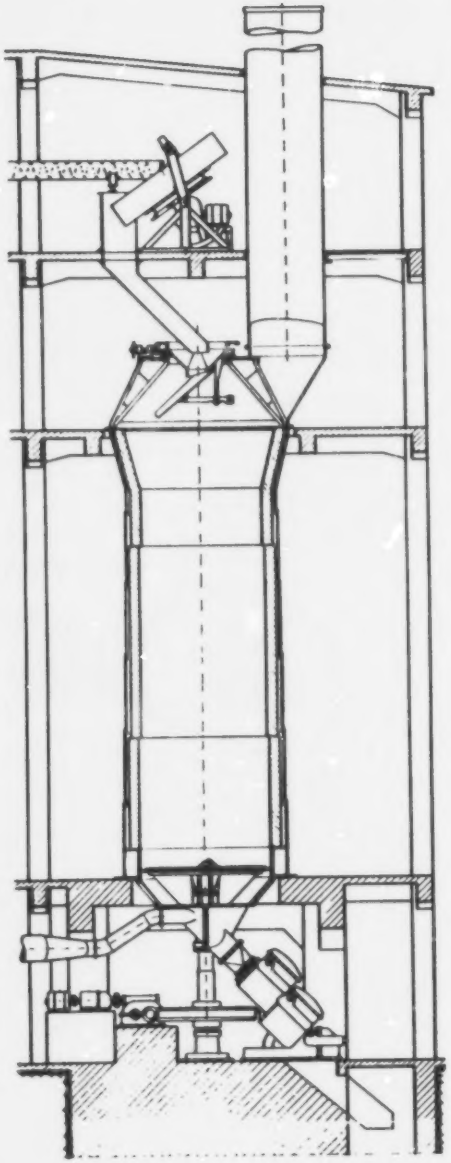

Fig. 1. Conventional Shaft Kiln
(Dr. Hans Kühl, Zement-Chemie, Vol. II,
VEB Verlag Technik Berlin, 1958)

FORTY YEARS OF SHAFT KILN DEVELOPMENT

THE CONVENTIONAL SHAFT KILN

The conventional shaft kiln is basically shown in Fig. 1. This kiln has been built with minor variations by a number of machine factories. The lower shaft has a diameter of 2.50 m (8 ft 2.4 in.). Its height varies between 7 and 10 m (23 and 33 ft). Daily capacity is 130 to 190 tons. The clinker leaves the kiln through an air lock with three gates. (Fig. 2) They are controlled mechanically or by a hydraulic device and should stand a kiln pressure up to 2000 mm WS or approximately 3 psi. Several types of grates are known: the rotary grate (Fig. 3), the Humboldt roller grate (Fig. 4), the Thiele grate (Fig. 5), and some others. The function of all these types is basically the same; they break up the hard burnt clinker and let it freely pass through the openings. Loose underburnt will not be retained. It falls through the openings immediately. This is a disadvantage. Once the kiln has a spot of weak fire, the material floods down at this spot, and it is very difficult to restore the fire at this spot. Kiln operation is always in a labile balance which can only be held up by artificial means. In consequence, these kilns are always run with some excess fuel in order to prevent weak spots. We will see later how seriously clinker quality is affected by this fuel excess.

Originally, the kiln shaft was cylindrical. About 1936, I introduced a conical shape of the sintering zone which has been adopted meanwhile by all kiln manufacturers*. The idea is to compensate the peripheral gap which is formed by the shrinkage of the material during burning. (Fig. 6) Through this gap, air would escape and is missing at the center where the fire moves down. There is a long and reducing sinter fire and a short peripheral fire. Upon the deep sinter fire rests the whole weight of the kiln load, and the soft sintering material is densely compacted. It becomes impermeable for the air and the previous air deficiency becomes still worse. Such a compact clinker cannot be properly cooled. It leaves the kiln almost red hot. The conical sintering zone (Fig. 7) mentioned before, brings a substantial improvement of the air distribution. However, it only works properly if the decrease in diameter corresponds with the shrinkage, and if its length corresponds with the length of the sintering zone. Shrinkage may vary with varying conditions and the length of the sintering zone is influenced by several factors, mainly the size of the nodules and the fuel particle size. Both are frequently ignored and are not kept under control. Therefore, at some installations the cone is a failure, because they have simply copied the dimensions of the Blaubeuren kilns without regard to local conditions.

The tendency of a weak peripheral fire is further increased by inadequate liner insulation of many older kilns. Heat loss seems to be almost negligible in relation to the whole kiln load. Actually, only a thin peripheral layer is affected by a sensible temperature drop. This thin layer will be underburnt, or if enough fuel is used to avoid underburning, the rest of the kiln load will be overburned and the surplus of additional fuel

*"The Shaft Kiln With Conical Burning Zone," Zement-Kalk-Gips, p. 215, 1949.

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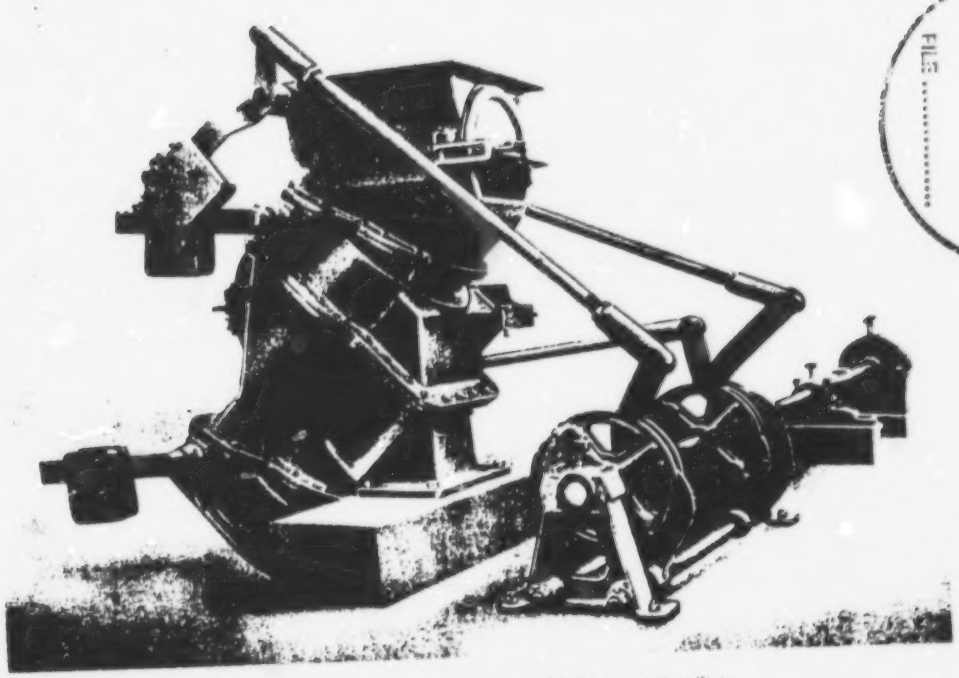

Fig. 2. Air Lock (Klöckner-Humboldt-Deutz A. G. Köln)

Fig. 2(a). Air Lock, Closed

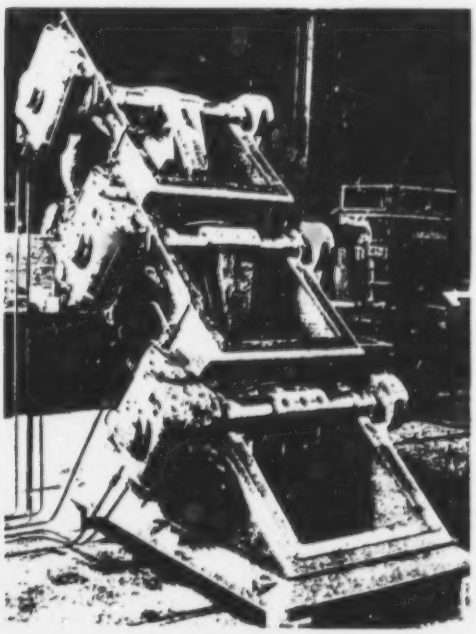

Fig. 2(b). Air Lock, Open

(Loesche, Hartzerkleinerungs-u. Zementmaschinen K. G. Düsseldorf)

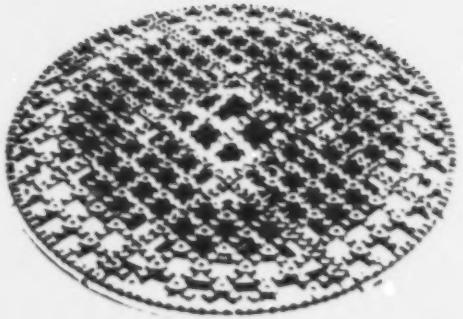

Fig. 3. Rotary Grate (Loesche, Hartzerkleinerungs-u. Zementmaschinen K.G. Düsseldorf)

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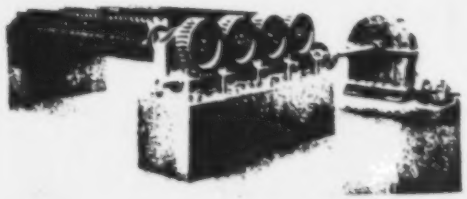

Fig. 4. Humboldt Roller Grate (Klöckner-Humboldt-Deutz A. G. Köln)

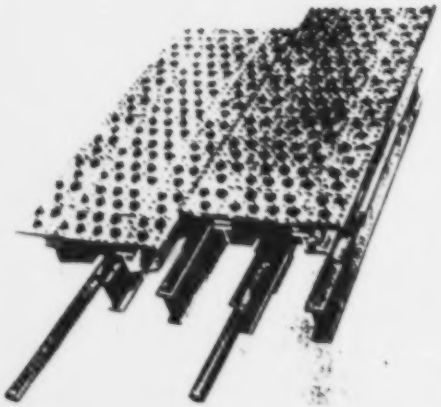

Fig. 5. Thiele Grate (Gebr. Pfeiffer, Kaiserslautern) (Dr. Hans Kühl, Zement-Chemie, Vol. II, VEB Verlag Technik Berlin, 1958)

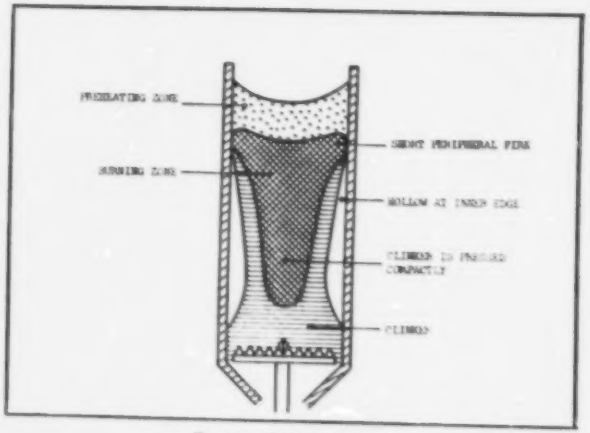

Fig. 6. Cylindrical Kiln

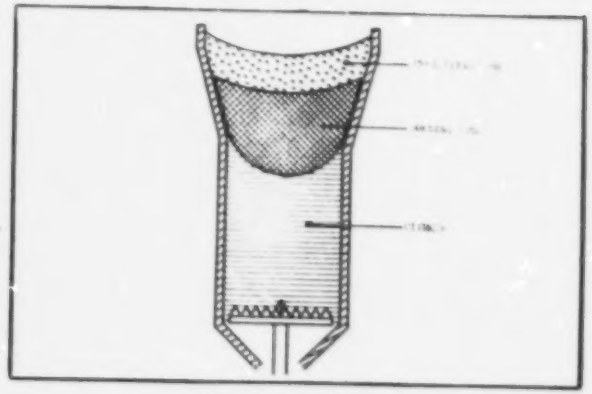

Fig. 7. Conical Kiln

is wasted as CO. Consequently, a much higher fuel consumption results than would be necessary to compensate the general heat loss of the kiln shell. This phenomenon has been described and analyzed by Eigen*. His description is fundamentally correct, in spite of the fact that the figures of his example do not apply for our kilns at Blaubeuren.

The kiln is usually fed by a rotating chute. (Fig. 1) The raw mix, including fuel, is pelletized by a pug mill, a roller press (Fig. 8), a drum (Fig. 9), or disc-pelletizer. (Fig. 10)

Exact proportioning of raw mix and fuel is of the highest importance. Most existing installations, including some proportioning scales, are inadequate. Also, the size of fuel is often neglected. It varies considerably between 0 and 6 mm. This is of some influence on the uniformity of the kiln operation.

The blower should be of such a type that air flow is not affected by varying kiln pressure. Pressure may vary between 800 and 2000 mm WS

*"The Importance of External Radiation Losses on the Economics of Lime and Cement Shaft Kilns," Zement-Kalk-Gips, pp. 392-396, 1958.

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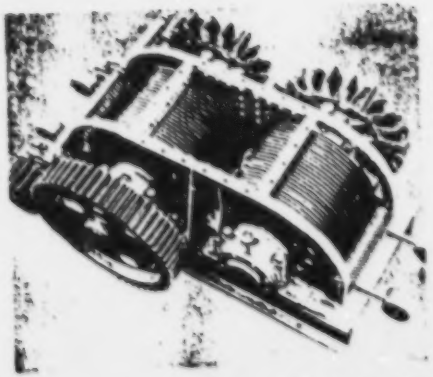

Fig. 8. Roller Press (Dr. Hans Kühl, Zement-Chemie, Vol. II, VEB Verlag Technik Berlin, 1958)

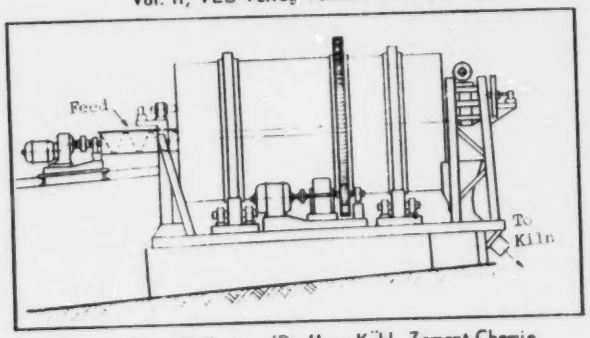

Fig. 9. Drum Pelletizer (Dr. Hans Kühl, Zement-Chemie, Vol. II, VEB Verlag Technik Berlin, 1958)

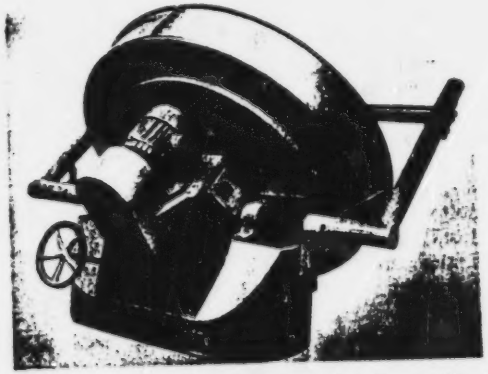

Fig. 10. Disc Pelletizer (Dr. Hans Kühl, Zement-Chemie, Vol. II, VEB Verlag Technik Berlin, 1958)

(1 and 3 psi). The outlay for the air flow is 180 to 200 cbm/min. (6500 to 7000 cu ft/minute).

CLINKER QUALITY OF CONVENTIONAL KILNS

The difficulties with these conventional shaft kilns can be seen in the formation of several zones. The peripheral zone has the tendency to produce underburnt in a short oxidizing fire. (Fig. 11) The center fire tends to be long and has a reducing atmosphere. In this zone compacted and reduced clinker is formed. (Fig. 12) Due to poor porosity, cooling velocity is extremely slow. There is also a certain amount of black, porous, quickly-cooled clinker. (Fig. 13) Such ideal clinker, however, seldom prevails. If it does prevail for some time this loose (or friable stuff) rushes through the grate irregularly here and there, and the ideal short fire soon is torn to pieces. Therefore, the operator prefers to burn with a longer, hotter fire, and to produce compact clinker lumps.

Our investigations of the different kinds of clinker brought big differences in quality. The porous black clinker has excellent properties which compare well with good rotary clinker. (Fig. 14) If the fuel is high in ash, however, there is a local contamination around each spot where a coal grain was before. (Fig. 15)

The underburnt usually occurs in small amounts. These small amounts are quite harmless, unlike rotary underburnt. It slakes easily with water and is no menace to expansion. We even like a certain small amount of underburnt. It improves plasticity and prevents bleeding. Such a cement is preferred to rotary cements for concrete pumping. One should keep in mind that the fineness of shaft kiln cements should not be determined by surface methods like Blaine. A very small amount of superfine slaked particles may be mistaken as clinker surface. They give no corresponding contribution to strength, however. We use a modified fluorometer (Fig. 16) and determine the plus +34 micron size.

Really poor is the overburnt, in spite of the fact that apparently it looks quite good. It shows dangerous expansion and has poor strength. In the microscope it can be shown (Fig. 17) that the alite has disintegrated partially into C_2S and secondary free lime. Dr. Woermann found that this disintegration is always connected with reducing kiln atmosphere. Moreover, such a clinker is often slowly cooled. All this is enough explanation for the generally bad reputation of the shaft kiln, in spite of the fact that some conventional shaft kiln plants in our country always had a quality over the average. The fact remains that the top quality of Type PZ 475 could not be met with this process. To make things worse, most shaft kiln plants had been built throughout in the most primitive way by very small companies. Raw mix, fineness, and homogeneity was not adequate. Recording instruments and automatic control was widely unknown to them. Measured on standards of twenty years ago, this may have been good enough, but not anymore today. Our new fuel-saving process, which will be described now, is by no means less sensitive to an inadequate raw mix than an up-to-date ACL kiln. There is no sense in modernizing just the kiln of a primitive outfit and maintaining the inadequate raw side. I could name a recent example of this kind of "economy."

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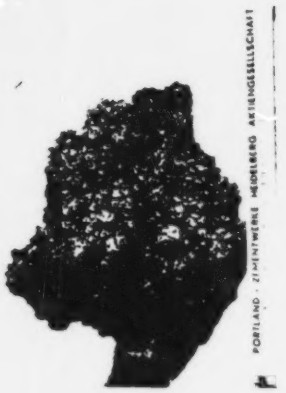

Fig. 13. Well Burnt Porous Clinker
(Scale in centimeters)

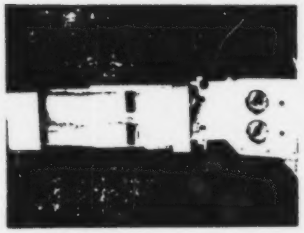

Fig. 16. Fineness Analyzer
(Alpine Company, Augsburg)

Fig. 17. Disintegrated Alite

Fig. 17(a). Disintegrated Alite

Fig. 12. Reduced Clinker
(Scale in centimeters)

Fig. 15. Ash + Reduction

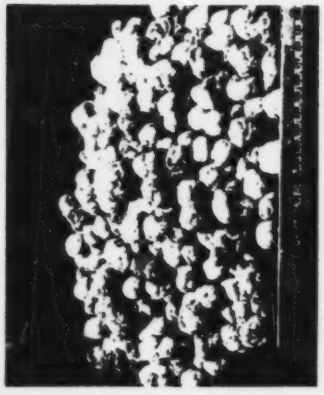

Fig. 11. Underburnt
(Scale in centimeters)

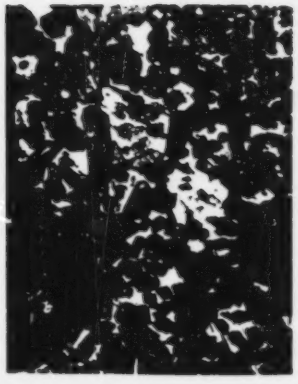

Fig. 14. Well Burnt Clinker (Section)

INTERGROUND FUEL PROCESS

At our Blaubeuren plant, we developed a new patented process which eliminates the failures described above. Raw mix and fuel are interground. So the coal ash becomes an integral part of the mix which is homogenized altogether. There is no ash contamination anymore. The fuel has uniform size. Therefore, the length of the burning zone can easily be controlled by the pellet size and adapted to the cone-shaped kiln liner. Normally, there is no poking necessary anymore to keep the material moving evenly.

A deficiency of air does not produce an elongation of the burning zone even when no oxygen is present. All fuel is volatilized according to Hauenschild's equation (simplified) $CaCO_3 + C = 2CO + CaO$. Pellets taken out of the burning zone and cooled quickly prove that. (Figs. 18 and 19) The previous calcining and sintering zones with uniform temperatures over a distance of several feet have shrunken down to millimeter distance within each pellet. Thus, the clinker stays porous and oxidized. It cools very rapidly. In fact, the clinker may be burnt and cooled quicker than in a rotary kiln. The whole process occurs in a short zone at the kiln top in spite of the fact that the kiln height of 8 m (26 ft) has been maintained for other reasons.

There is no more reduced clinker unless the fuel was not ground fine enough or had an extremely low reactivity. We found the best reactivity with lignite coke, anthracite, and petrol coke. Then follow gas coke and blast-furnace coke.

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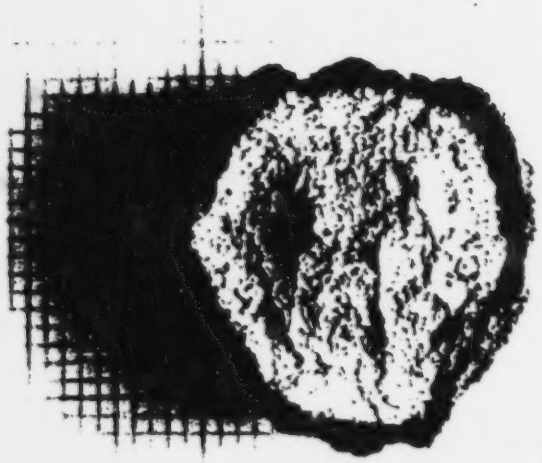

Fig. 18. Hauenschildt Reaction

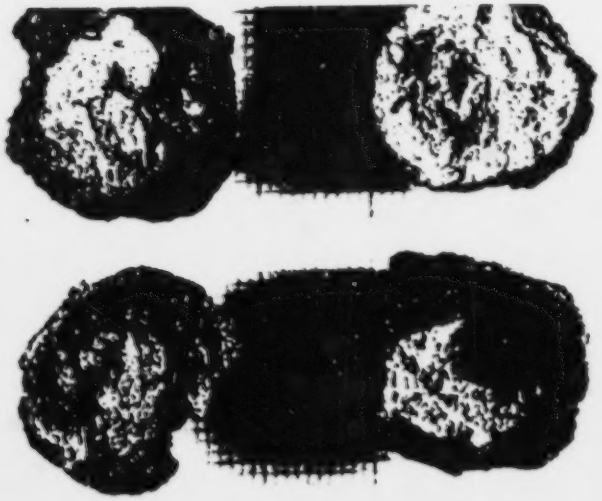

Fig. 19. Hauenschildt Reaction

Usually clinker pellets are not fused together. They stay loose like rotary clinker. (Fig. 20) They are lighter in their specific weight with characteristic voids. (Figs. 21 and 22) The mineralogic picture shows no basic difference to that of good rotary clinker.

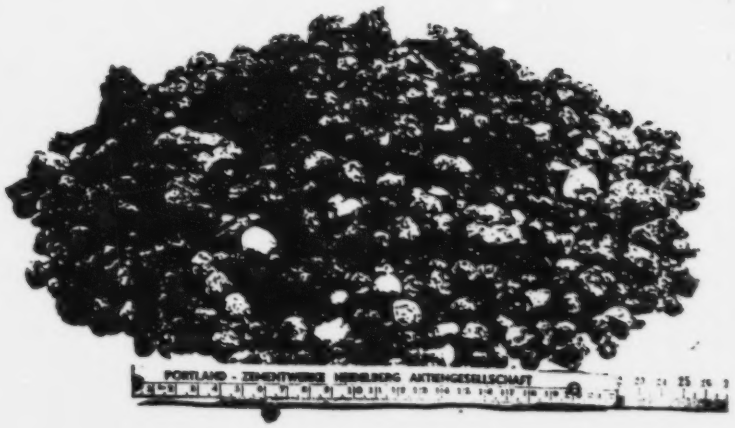

Fig. 20. Loose Clinker (Scale in centimeters)

Fig. 21. Agglomeration of Pellets with Voids

Fig. 22. Voids (Section)

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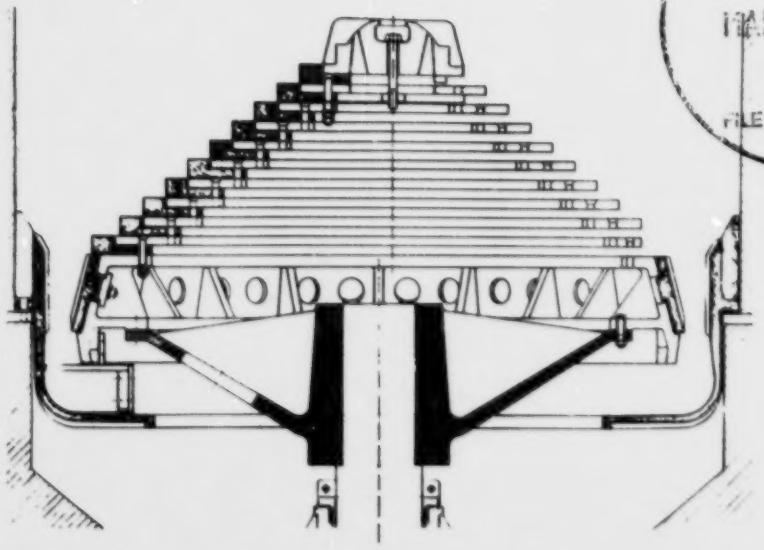

Fig. 23. New Grate

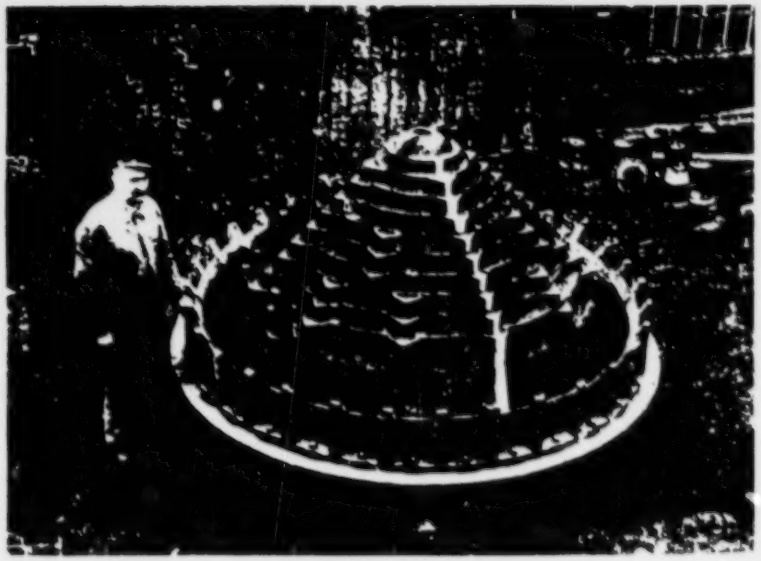

Fig. 24. New Grate

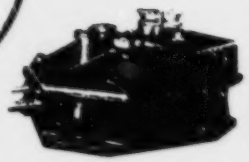

Fig. 25. Gear for Grate (Loesche, Hartzerkleinerungs-u. Zementmaschinen K. G. Dusseldorf)

Fig. 26. Grate Test With Loose Clinker

Fig. 27. Grate Test With Loose Clinker

Such loose and friable clinker cannot be handled by conventional shaft-kiln grates. We developed a novel rotary grate (Figs. 23 and 24) which forces quite evenly compacted, friable or loose material, or any mixture of it, out of the kiln. It does not tear up our short burning zone. The grate can be fitted into older kilns. In new installations a closed gear box is preferred. (Fig. 25) Figs. 26 and 27 show an experiment with a kiln filled up with crushed clinker and gradually emptied by the grate. The material flow has become quite even and the operation stabilized. Rat holes which formerly were very frequent and made hand operation necessary, have almost disappeared. Now, one operator handles two or three kilns. Feed is automatically controlled by the flue gas temperature. The constant flue gas temperature (Fig. 28) now enables us to use electric precipitators which completely retain dust and alkali fumes. Fig. 29 shows a plant with five kilns without precipitators. The shaft kilns remove more alkali from the mix than the Lepol kiln at the same plant. Fig. 30 shows the same plant later with an electric precipitator at the shaft kilns and a new Lepol kiln with high stack.

Over some longer period, we tried to feed the kiln with a finer-ground raw mix. The result was a good Type PZ 475, the highest early-strength cement which is made only by 17 rotary plants in Western Germany. It has a relatively small market.

Our present raw mill is too small, however, since the fuel consumption was lowered approximately ten per cent by the intergrinding process and another ten per cent by the coating process which is mentioned later. According to the lower fuel consumption, the kiln capacity went up to 200 tons. That is why our raw mill is a bottleneck, and we grind our mix as coarse as our Type PZ 275 standard allows. Still, we have one of our five kilns standing idle most of the time. A new mill will be in operation next year, and we will be able to adjust our clinker quality to a higher standard.

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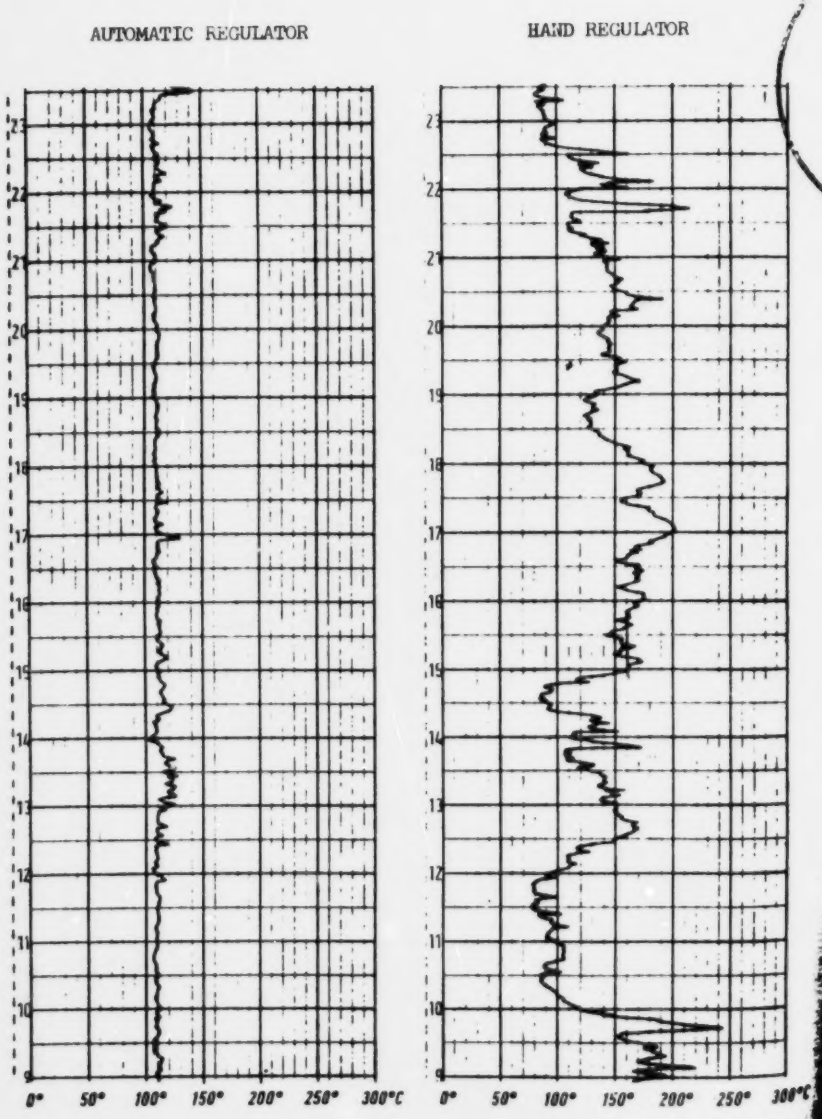

Fig. 28. Flue Gas Temperature

Fuel is the No. 1 cost factor in Europe. Therefore, we introduced an additional improvement, the COATING PROCESS. It brought another substantial reduction in fuel consumption. By a fuel-free raw-mix coating around the pellet, the coal is protected against the hot flue gas in the preheating zone. So the Boudouard reaction $CO_2 + C = 2CO$ will not occur in that zone as usually happens in all shaft kilns and gas producers. With a comparatively thin shell, we already had coal savings of ten per cent. There is still CO in the flue gas, and we now have made provisions for a thicker shell and hope for a better result than the 800 kcal/kg clinker we approximately had so far. We also intend to test to see whether a complete combustion of lignite coal is possible with that process. For that purpose, a still thicker coating might become necessary.

SHAFT KILN VS. ROTARY KILN

How might the modern shaft kiln now compete with the rotary kiln? To sum it up briefly, we might say that the modern shaft kiln can meet the highest quality standards, provided the raw mix was made with at least the same care as for a modern rotary kiln. The same applies for instrumentation, automatic controls, proportioning scales, et cetera.

A 2.5 m kiln of 200 tons daily capacity has less initial cost than a rotary kiln of comparative size. (Fig. 31) Also, the production costs are usually lower. Three meter kilns already may be had, and I believe that further enlargements will be possible to an upper limit of 300 tons. For kiln sizes of 150 to 300 tons, the shaft kiln will be preferable to the rotary kiln. When we suppose that a plant is better off with two kilns than with one kiln, the shaft kiln should be superior; for a first step generally between 2 x 150 = 300 tons, and 2 x 300 = 600 tons. A later extension up to 5 x 300 tons = 1500 tons may be considered. In highly industrialized countries, units of more than 600 tons for the first step are usually considered. This calls for a preference of the rotary kiln.

However, kiln size is not the only determining factor for the choice. The local price situation for fuel also must be considered. The shaft kiln can utilize any high ash content up to 30 or 40 per cent. The best quality is lignite coke, anthracite or petrol coke. Gas coke and blast-furnace coke is very acceptable. High volatile fuels formerly were not acceptable. It has not yet been tested to see if these may be used with our coating process.

There are a number of countries in which high-ash anthracite fines are going to waste. For that situation the shaft kiln has no competition.

The old conventional shaft kiln, as it has been generally known, is not considered by the author as competitive with modern rotary kilns in regard to quality, labor, and fuel costs. Modern shaft kilns, however, with interground fuel and the coating process, may be superior to rotary kilns under certain conditions, especially for smaller plants.

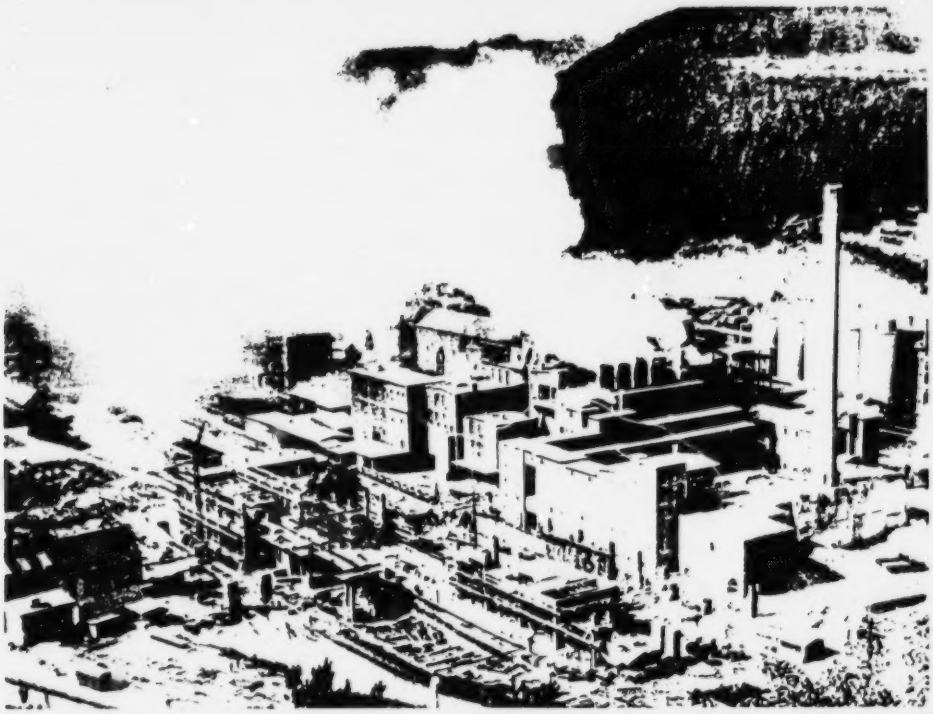

Fig. 29. Plant Without Electric Precipitator

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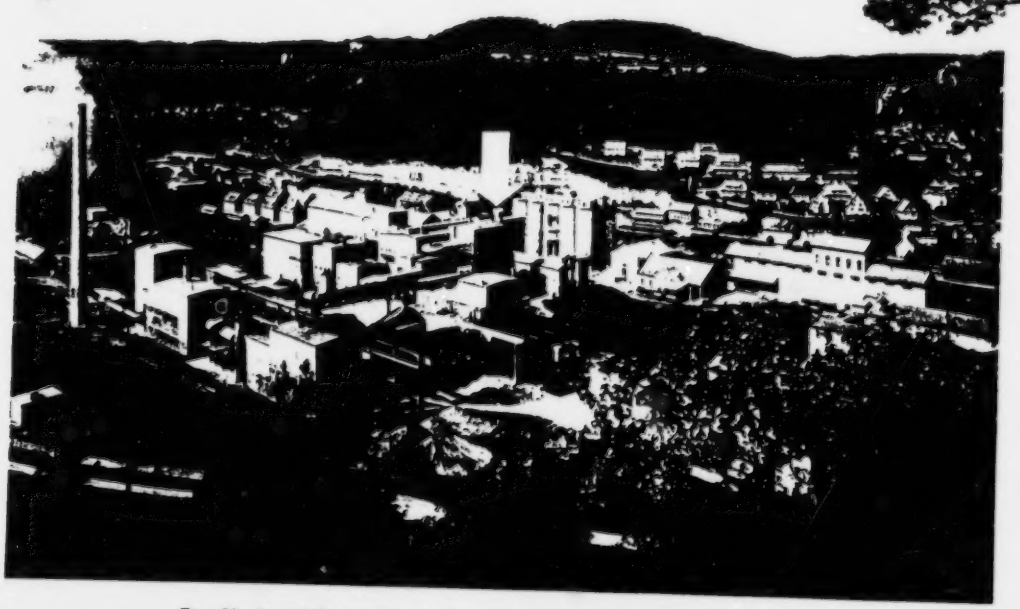

Fig. 30. Lepol Rotary Kiln in Operation Without Electric Precipitator and Five Shaft Kilns in Operation With Electric Precipitator. (See Arrow)

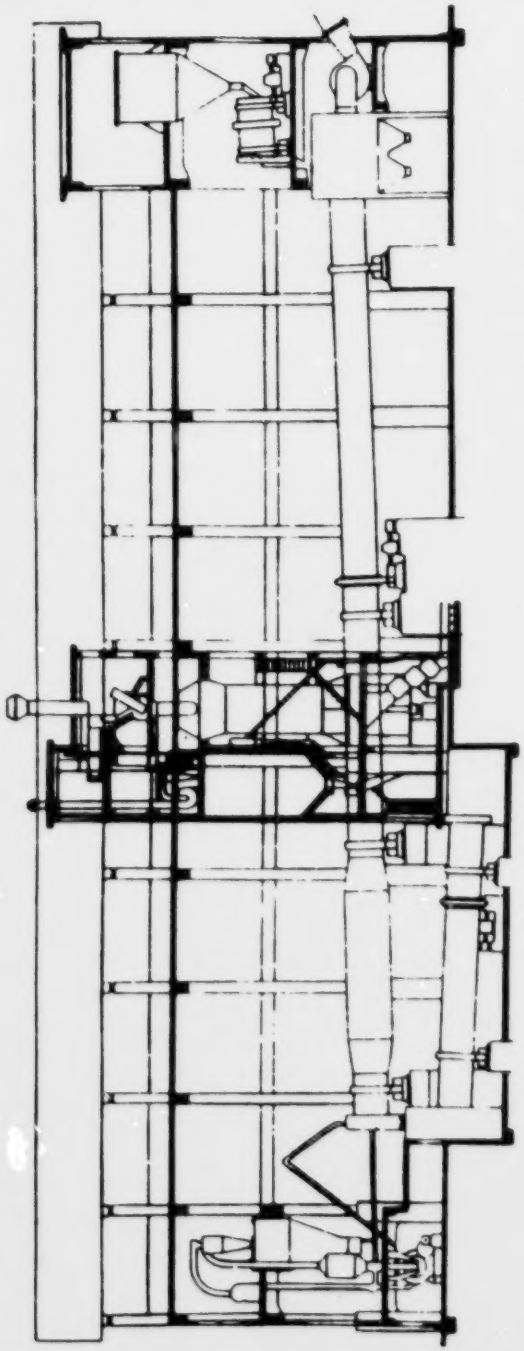

Fig. 31. Comparison of Space for Shaft Kiln and Rotary Kiln
(L. de Roll S. A., Zürich, Switzerland)

SUMMARY

(1) The conventional shaft-kiln process is discussed. Its well-known disadvantages are analyzed, especially inadequate clinker quality due to reducing atmosphere.

(2) Excellent clinker quality has been produced with a new process of using interground fuel and a special grate.

(3) The "interground fuel process" can be combined with the "coating process." Twenty per cent fuel savings against the conventional process have been achieved.

(4) Situations are discussed for which such a modern shaft kiln may be superior to the rotary kiln. For smaller units shaft kilns always should be considered.

A new field for the shaft kiln is the sintering of fly ash. Fly ash usually contains enough fuel to be sintered without additional fuel. Here, too, the new grate is the key to success. Loosely burnt nodules can be well handled, and such a smooth rounded aggregate is preferred to an overburnt and crushed one. Loesche has a plant now being erected in the Netherlands.

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APPENDIX D

Cement Standards of the C.S.A. and the A.S.T.M.

NATIONAL STANDARD OF CANADA CAN3-A5-M83

PORTLAND CEMENTS

Prepared by
CANADIAN STANDARDS ASSOCIATION

Approved by
STANDARDS COUNCIL OF CANADA

ISSN 0317-5669
PUBLISHED IN MAY, 1983 BY CANADIAN STANDARDS ASSOCIATION, 178 REXDALE BOULEVARD, REXDALE (TORONTO), ONTARIO, CANADA M9W 1R3

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CAN3-A5-M83
Portland Cements

1. Scope

1.1 Scope. This Standard sets forth the definition of Portland cement; chemical, physical, and uniformity requirements; tests required, procedures for inspection and sampling; units of measurement, packaging, marking, and storage; methods for chemical analysis; methods for physical testing; and equipment and materials used in performing the required tests.

1.2 Types. The 5 types of Portland cements covered in this Standard are identified as follows:

English		French
Name	**Type**	**Name**
Normal Portland Cement	10	Ciment portland normal
Moderate Portland Cement*	20	Ciment portland modéré
High Early-Strength Portland Cement	30	Ciment portland à haute resistance initiale
Low Heat of Hydration Portland Cement	40	Ciment portland à faible chaleur d'hydratation
Sulphate Resistant Portland Cement	50	Ciment portland résistant aux sulfates

**Moderate with respect to heat of hydration or sulphate resistance.*

1.3 Reference Publications. This Standard refers to the following publications and where such reference is made it shall be to the edition listed below, including all revisions published thereto:

CSA Standards
A5-1971,
Portland Cements (now withdrawn);

Supplement No. 1-1977 to A5-1971,
Portland Cements;

CAN3-A23.1-M77,
Concrete Materials and Methods of Concrete Construction;

A82.20-M Series 1977,
Methods of Testing Gypsum and Gypsum Products;

B51-M1981,
Code for the Construction and Inspection of Boilers and Pressure Vessels;

ASTM* Standards
C114-82a,
Chemical Analysis of Hydraulic Cement;

C186-82,
Heat of Hydration of Hydraulic Cement;

C465-74 (Reapproved 1979),
Processing Additions for Use in the Manufacture of Hydraulic Cements;

C778-80a,
Standard Sand;

E1-82,
ASTM Thermometers;

CGSB† Standard
8-GP-2M-1976,
Sieves, Testing, Woven Wire, Metric;

American Chemical Society Specifications for Reagent Chemicals — 1981;

United States National Bureau of Standards Circular 547, 1954.

**American Society for Testing and Materials.*
†Canadian General Standards Board.

2. Definition

2.1 The following definition applies in this Standard:

Portland cement means the product obtained by pulverizing clinker consisting essentially of hydraulic calcium silicates to which calcium sulphate, limestone*, water, and processing additions† may be added at the option of the manufacturer.

**The Committee recognizes the existence of an optimum carbonate addition for some Portland cements. Therefore, a maximum of 5% addition of limestone is permitted for Normal Portland cement. Such limestone shall be of a quality suitable for the manufacture of Portland cement clinker.*
†Processing additions may be used, provided that such materials, in the amounts used, have been shown to be not harmful in accordance with ASTM Standard C465, Processing Additions for Use in the Manufacture of Hydraulic Cements.

3. General Requirements

3.1 Chemical Requirements

3.1.1 Portland cement of each type shall conform to the respective chemical requirements stipulated in Table 1.

3.1.2 Analytical procedures other than those outlined in Clause 6 may be used for cement acceptance; however, all referee tests shall be carried out in accordance with Clause 6.

3.1.3 When aggregates have been tested by methods prescribed by CSA Standard CAN3-A23.1-M, Concrete Materials and Methods of Concrete Construction, Appendix B, and demonstrated to be potentially deleteriously reactive, special precautions shall be taken to ensure that the total alkali content of a concrete mixture does not produce a deleterious alkali-aggregate reaction.

In such cases, when requested by the purchaser, the cement manufacturer shall report the total alkali content of Portland cement, expressed as $(K_2O \times 0.658) + Na_2O$. For methods of test for alkalies in cement, refer to ASTM Standard C114, Chemical Analysis of Hydraulic Cement.

3.2 Physical Requirements

3.2.1 General. Portland cement of each type shall conform to the respective physical requirements stipulated in Table 2, except as noted in Clause 3.2.2, when tested in accordance with the procedures set out in Clause 7.

3.2.2 Retest

3.2.2.1 Soundness. Cement failing to meet the soundness requirement stipulated in Table 2 shall not be considered to have failed when, after resampling and retesting within 28 days, it meets the requirement.

3.3 Uniformity Requirements

3.3.1 General. The coefficient of variation of the 28-d compressive strength of Normal Portland cement shall not exceed 8.0% when calculated in accordance with the procedures set out in Clause 9. Only cement represented by the most recently taken sample and which causes the coefficient of variation to exceed or remain beyond 8.0% shall be considered to have failed the uniformity requirements.

3.3.2 Time of Test. Testing of each sample taken for uniformity compliance shall be completed within 8 weeks of sampling.

4. Testing, Inspection, and Sampling

4.1 Samples to be Tested. Tests shall be made on single or composite samples taken, identified, and prepared as required by this Clause, of cement produced or of cement sold or offered for sale in bulk or bags.

4.2 Tests by the Manufacturer

4.2.1 Portland cement shall be tested by the manufacturer to ensure compliance of cement produced with the requirements of Clause 3.

4.2.2 Where process control at the cement plant is by methods other than those specified in Clauses 6 and 7, tests shall be conducted in accordance with the methods specified in Clauses 6 and 7, at such intervals as are required to confirm the adequacy of the other methods in use and to furnish the typical test data and/or certificate specified in Clause 4.6.

4.3 Tests by the Purchaser

4.3.1 Where the purchaser requires testing of Portland cement for compliance with the requirement of Clause 3, the tests shall be made on samples of lots of bulk or bagged cement, sold or offered for sale, that are individually identifiable.

Note: *Individual identifiable lots are lots such as truck(s), rail car(s), boat(s), or silo(s), or bagged cement in storage or shipment that are identified at the time of sampling in accordance with Clause 4.9.*

4.3.2 The cost of tests on individual identifiable lots made at the request of the purchaser shall be borne by the purchaser unless otherwise provided by prior agreement between the vendor and the purchaser.

4.3.3 If specified by the purchaser, the place of testing of individual identifiable lots shall be determined by him.

4.4 Frequency of Testing. Except in the case of tests by the manufacturer on samples of production (see Clause 4.2) or where tests on single samples of individual identifiable lots of smaller size are required by the purchaser, the following frequency of testing is considered desirable for indicating compliance of Portland cement with the requirements of Clause 3:

(a) **Physical Tests—Table 2:**

(i) Time of setting — 1 test for each 500 t (single sample);

(ii) Fineness — 1 test for each 500 t (composite sample);

(iii) Strength — 1 test for each 1000 t (composite sample);

(iv) Soundness — 1 test for each 500 t (composite sample);

(v) Heat of Hydration — 1 test for each 2000 t (composite sample);

(vi) Sulphate Resistance — 1 test for each 2000 t (composite sample);

(b) **Chemical Tests—Table 1:**

(i) Sulphur Trioxide (SO_3) — 1 test for each 500 t (composite sample);

(ii) All other chemical tests — 1 test for each 1000 t (composite sample).

4.5 Optional Tests. Tests for the following requirements stipulated in Table 2 may be waived at the option of the purchaser:

(a) Sulphate Resistance;

(b) Heat of Hydration; and

(c) 28-d Compressive Strength.

4.6 Provision of Typical Test Data or Certificates. The vendor shall furnish, when requested, typical test data of cement sold or offered for sale and/or provide a certificate that the cement meets the requirements of the Standard specified at the time of purchase.

4.7 Test Reports

4.7.1 The testing agency shall furnish a report, immediately upon the completion of testing, of the results of all tests made, referencing the sample of cement tested to the identification provided with the sample as specified in Clause 4.9.

4.7.2 The test report shall certify that all tests were made in accordance with the requirements of this Standard, or shall state any departures from the requirements.

4.7.3 A reasonable period of time shall be allowed for testing and the reporting of test results.

4.8 Inspection and Sampling—General

4.8.1 Cement shall be subject to inspection and sampling at the place of manufacture, at the point of shipment, or on delivery; and if specified by the purchaser, the place of inspection and sampling shall be determined by him.

4.8.2 The vendor shall afford the facilities for inspection and sampling, for taking and packing the samples, and for identifying the cement at the place of manufacture or the point of shipment.

4.8.3 A reasonable period of time shall be allowed for inspection, sampling, and shipping of samples to the place of test.

4.8.4 Samples shall be taken without undue delay in accordance with the methods described in Clause 4.12 and, if required by the purchaser, this shall be done by or under his direction.

4.8.5 Every possible precaution shall be observed in securing, handling, and preparing samples for testing, to avoid contamination and to ensure the sample represents, and is identifiable with, the cement sampled.

4.8.6 At the time of inspection for acceptance on delivery or when sampled, bagged cement shall be in packages that are whole and in good condition and bulk cement in storage shall be in weathertight containers and free of contamination by foreign material or deterioration due to moisture.

4.8.7 The costs of inspection and sampling of individual identifiable lots shall be borne by the purchaser unless otherwise provided by agreement between the vendor and purchaser.

4.9 Identification of Lots and Samples. Each test sample shall be clearly identified by inclusion or attachment of the following information in or to the sample container:

(a) Test sample number (samples shall preferably be numbered consecutively);

(b) Name of cement company and/or supplier;

(c) Name of the cement or type, as defined in Clause 1.2, and brand where known;

(d) Time, date, and location of sampling;

(e) Quantity of cement represented by the sample;

(f) Type of sample (single or composite);

(g) Identification of lot(s) included in the sample, such as truck(s) number, rail car(s) number, boat and hold number, container or silo number; and

(h) Name and signature of the sampler.

This identification shall be maintained throughout testing and the reporting of test results.

4.10 Type and Size of Samples

4.10.1 A test sample is defined as the amount of cement necessary to provide material for the tests required by Clause 4, and shall be representative of cement produced or of individual identifiable lots sold or offered for sale.

4.10.2 Test samples shall be as specified in Clause 4.4(a) or (b) for particular tests, either single samples made up of small increments thoroughly blended or composite samples made up of 2 or more portions of single samples.

4.10.3 No single sample shall represent more than 500 t of cement nor be less than 4 kg. No composite sample shall represent more than 2000 t of cement; the quantity selected shall be based on the intended test or tests.

4.11 Frequency of Sampling. The frequency at which single samples shall be taken is determined by the number of samples, composited as necessary, required for testing in accordance with frequency of testing specified in Clause 4.4.

4.12 Methods and Equipment for Taking Single Samples

Note: *Automatic sampling methods are preferred over manual methods for the sampling of production or of bulk cement at the time of discharge from storage or of bagged cement during the bagging operation.*

4.12.1 Automatic Sampling Devices. Automatic sampling devices shall be of a type that does not preferentially sample one extreme of particle size and shall be placed in the circuit so that not more than 2 t of storage capacity exists between the sample and the point of discharge.

4.12.2 Manual Sampling of Bulk Cement. In the absence of an automatic sampler, small equal increments shall be scooped from the discharge flow at intervals of not more than 2 t. At least 20 such increments shall be included in each single sample.

4.12.3 Manual Sampling of Bagged Cement. In the absence of an automatic sampler at the bagging operation or where samples are required from cement already bagged and in storage, small increments shall be taken from the bags by means of a sampling tube inserted to the centre of the bag. The lot being sampled shall be represented by a test sample containing not less than 20 increments. The interval between increments shall not exceed 125 bags (40 kg each).

Note: *A suitable sampling tube for use as described in Clause 4.12.3 is shown in Clause 8.4.6.*

4.12.4 Sample Containers. Samples shall be packed in moisture-proof airtight containers.

4.13 Compositing of Single Samples. Composite samples required for tests, as defined in Clause 4.4, shall be prepared by arranging all the consecutive single samples to be included in the composite sample in groups, each group representing the lots or quantity of cement for which the composite sample is intended. From each of the single samples in a group, equal portions shall be taken, sufficient in amount to form a composite sample large enough for the required physical and/or chemical tests. The composite sample thus prepared and identified in accordance with Clause 4.9 shall be stored in moisture-proof airtight containers. Prior to use, the composite sample shall be thoroughly blended to achieve uniformity.

4.14 Sieving. Immediately prior to testing, all test samples shall be thoroughly mixed and then passed through a 710-μm sieve to break up lumps and remove foreign matter. Hardened lumps not broken by sieving or brushing and foreign material shall be discarded. The sieved cement shall be stored in a moisture-proof airtight container prior to performance of each test.

4.15 Splitting of Test Samples. Single samples or composite samples that require portioning for individual tests, or

portions of single samples that are taken for the preparation of a composite sample, shall be divided in such a manner as to ensure representative portions.

Note: *Riffling or quartering down of the sample is recommended for this purpose.*

5. Units, Packaging, Marking, and Storage

5.1 Units for Bulk Cement. Bulk cement shall be measured in tonnes.

5.2 Packaging

5.2.1 Bags shall contain 40 kg net.

5.2.2 The average net mass of 25 bags taken at random shall be not less than 1000 kg.

5.3 Marking

5.3.1 Bagged Cement. Cement in bags shall plainly exhibit the following information:

(a) The name of the cement company;

(b) The name and type of cement as defined in Clause 1.2; and

(c) The net mass of the contents.

5.3.2 Bulk Cement. When cement is shipped in bulk, the same information as required for bagged cement in Clause 5.3.1 shall be contained in the invoices accompanying the shipment.

5.4 Storage. Cement shall be kept in weathertight storage that will protect it from moisture and contamination, and in such a manner as to permit inspection, sampling, and identification, where required, of each lot.

6. Methods for Chemical Analysis

6.1 Equipment and Materials. The equipment and materials used in the chemical analysis of Portland cement shall conform to the requirements of the appropriate Clause listed in Table 3.

6.2 Chemical Analysis. Chemical analysis shall be performed in accordance with the appropriate Clause listed in Table 4.

6.3 Test Procedures

6.3.1 Loss on Ignition

6.3.1.1 Weigh 1 g of cement sample in a tared platinum crucible of 20—25 mL capacity and fitted with a cover. Place the crucible in a muffle furnace at a temperature of 1050 ± 50°C for 20 min. Cool it in a desiccator and reweigh. Check the loss in mass by subsequent 5-min ignitions until a constant mass is obtained.

6.3.1.2 Calculate the percentage of loss on ignition by multiplying the loss in mass by 100 and dividing by the original mass of the sample.

6.3.2 Insoluble Residue

6.3.2.1 Transfer 1 g of cement sample into a 250-mL beaker. Add 25 mL of cold water and, while stirring vigorously, 5 mL of HCl. Disperse any lumps that may have formed with the flattened end of the stirring rod, warming the solution gently if necessary, until decomposition is complete. Immediately dilute the solution to 50 mL with near-boiling water and heat the covered mixture rapidly to a temperature just below boiling. Digest the mixture at this temperature for 15 min. Filter the solution into a 400-mL beaker, wash the beaker, paper, and residue thoroughly with hot water and reserve the filtrate for the sulphur trioxide (SO_3) determination if desired (see Clause 6.3.3.1).

6.3.2.2 Transfer the filter paper and contents to the original beaker, add 100 mL of near-boiling NaOH solution (10 g/L), and disintegrate the filter paper with the stirring rod. Digest the mixture for 15 min at a temperature just below boiling. During the digestion, occasionally stir the mixture and further macerate the filter paper. Using methyl red as the indicator, acidify the solution with HCl and add 4 or 5 drops in excess. Filter and wash the residue a minimum of 14 times with hot NH_4NO_3 solution (20 g/L), making certain to wash the entire filter paper and contents during each washing. Place the filter paper and contents in a tared platinum crucible. Slowly char and ash the filter paper without inflaming and ignite to constant mass at a temperature of 1050 ± 50°C. Cool in a desiccator and weigh.

6.3.2.3 Make a blank determination following the same procedure and using the same amounts of reagents. Correct the mass of residue obtained in Clause 6.3.2.2 accordingly.

6.3.2.4 Calculate the percentage of insoluble residue by multiplying the corrected mass by 100.

6.3.3 Sulphur Trioxide (SO_3)

6.3.3.1 Dilute the filtrate obtained in Clause 6.3.2.1 to 250 mL with water and heat to boiling. While stirring, add 10 mL of hot barium chloride ($BaCl_2.2H_2O$, 100 g/L) drop by drop from a pipette, and continue boiling for 15 min. (A piece of filter paper about 1 cm^2 placed under the tip of the stirring rod during this period will prevent bumping.) Digest the solution at a temperature just below boiling for 3 h and at room temperature for 9—20 h. Filter the precipitate and wash it until chloride free [silver nitrate ($AgNO_3$) test]. Place the paper and contents in a tared platinum crucible. Slowly char and ash the filter paper without inflaming and ignite at a temperature of 850 ± 50°C for 30 min. Cool in a desiccator and weigh.

6.3.3.2 Make a blank determination following the same procedure and using the same amounts of reagents. Correct the mass of ignited precipitate obtained in Clause 6.3.3.1 accordingly.

6.3.3.3 Calculate the percentage of SO_3 by multiplying the corrected mass of barium sulphate ($BaSO_4$) by 34.3.

6.3.4 Tricalcium Aluminate (C_3A). Calculate the percentage of C_3A as follows: $C_3A = (2.65 \times \text{per cent } Al_2O_3) - (1.69 \times \text{per cent } Fe_2O_3)$.

6.3.5 Ferric Oxide (Fe_2O_3)

6.3.5.1 Transfer 1 g of cement sample to a 250-mL

beaker. Add 25 mL of water and while stirring add 10 mL of HCl. Disperse any lumps that may have formed with the flattened end of the stirring rod, and warm the solution gently until decomposition is complete. Dilute to 50 mL and heat to boiling. Add 5 mL of HCl. While stirring add $SnCl_2$ solution drop-wise until the solution in the beaker is decolourized. Add 1 drop in excess. Cool to room temperature, wash down the inside of the beaker and then add, all at once, 10 mL of a cool saturated solution of mercuric chloride ($HgCl_2$). Stir vigorously for 1 min. Add 15 mL of H_3PO_4 (1:1) and 2 drops of barium diphenylamine sulphonate indicator. Titrate with standard $K_2Cr_2O_7$ solution to a permanent deep blue colour.

6.3.5.2 Calculate the percentage of Fe_2O_3 as follows:

Per cent $Fe_2O_3 = EV \times 100$

where

E = Fe_2O_3 equivalent of the $K_2Cr_2O_7$ solution in grams per millilitre

V = millilitres of $K_2Cr_2O_7$ solution used in the titration

6.3.6 Combined Oxides of NH_4OH Group

6.3.6.1 Transfer 0.5 g of cement sample into a pyrex or porcelain evaporating dish of about 100-mL capacity. Add 10 mL of water and stir. Add 5 mL of HCl, cover with a watch glass, and digest with the aid of gentle heat and agitation until decomposition is complete. Remove and wash the watch glass, adding the washings to the solution in the dish. Evaporate to dryness on a steam bath. Remove and add 20 mL of HCl (1:1), cover with a watch glass, and digest 10 min on a steam bath. Remove and wash the watch glass, adding washings to the dish. Dilute the solution to about 50 mL with hot water and filter immediately into a 400-mL beaker. Wash the dish and separated solids with hot dilute HCl (1:99) and finally with hot water. Discard the filtered residue, silicon dioxide (SiO_2). Adjust the volume to about 200 mL, and add HCl if necessary to ensure a total of 10—15 mL of acid. Add a few drops of methyl red indicator and heat to boiling, add NH_4OH (1:1) drop by drop until the solution turns yellow, and then 2 drops in excess. Boil the solution about 1 min, set aside for not more than 5 min, and filter by decantation into a 600-mL beaker. Wash the hydroxides once in the original beaker and twice on the filter paper with hot ammonium nitrate (NH_4NO_3*, 20 g/L). Set the filtrate aside and transfer the paper and contents to the original beaker. Dissolve the precipitate in hot HCl (1:3), and dilute the solution to about 100 mL. Add a few drops of methyl red indicator, reprecipitate the hydroxides, boil and set aside as previously described. Filter the precipitate, and wash it with 2 portions of hot NH_4NO_3* (20 g/L). [Combine the 2 filtrates and retain for magnesia (MgO) determination.] Place the filter paper and contents in a tared platinum or porcelain crucible, slowly char and ash the filter paper without inflaming, and ignite to constant mass at a temperature of 1050 ± 50°C. Record the mass of precipitate.

**Two drops of methyl red indicator should be added to the NH_4NO_3 solution in the wash bottle, followed by NH_4OH (1:1) added drop by drop until the colour just changes to yellow. If the colour reverts to red at any time due to heating, it should be brought back to yellow by the addition of a drop of NH_4OH (1:1).*

6.3.6.2 Make a blank determination following the same procedure and using the same amounts of reagents. Correct the mass of ignited precipitate obtained in Clause 6.3.6.1 accordingly.

6.3.6.3 Calculate the percentage of the combined oxides of the NH_4OH group by multiplying the corrected mass by 200.

6.3.7 Alumina (Al_2O_3). Calculate the percentage of Al_2O_3 by subtracting the percentage of P_2O_5 and TiO_2, as determined by ASTM method C114, and the percentage of Fe_2O_3 from the percentage of combined oxides, NH_4OH group, or determine the percentage of Al_2O_3 directly using a method qualified according to ASTM Standard C114, Chemical Analysis of Hydraulic Cement.

6.3.8 Magnesia (MgO)

6.3.8.1 Acidify the combined filtrates from Clause 6.3.6.1 with HCl and evaporate to about 100 mL. Add 40 mL of saturated bromine water to the hot solution and immediately add NH_4OH until the solution is distinctly alkaline. Boil the solution at least 5 min, maintaining distinct alkalinity. Let the precipitate, if any, settle; filter and wash with hot water. Discard the filtered residue [mainly manganese dioxide (MnO_2)]. Acidify the filtrate with HCl and boil until all the Br_2 is expelled.

6.3.8.2 Dilute to about 200 mL. Add 5 mL of HCl, 25 mL of hot ammonium oxalate $(NH_4)_2C_2O_4.H_2O$ (50 g/L), and a few drops of methyl red indicator to the boiling solution. While stirring, slowly add NH_4OH (1:1) until the solution turns yellow. Allow the solution to stand without further heating for 1 h (no longer) with occasional stirring during the first 30 min. Filter and wash with a small amount of cold dilute $(NH_4)_2C_2O_4.H_2O$ (1 g/L). Set the filtrate aside. Wash the precipitate from the filter paper into the original beaker using a jet of hot water. Wash the filter paper with 50 mL of hot HCl (1:4) and complete washing with hot HCl (1:100), collecting the washings in the same beaker. Dilute to 150 mL, add 5 mL of $(NH_4)_2C_2O_4.H_2O$ (50 g/L), precipitate, filter and wash as previously described. Discard the filtered residue, calcium oxalate ($CaC_2O_4.H_2O$).

6.3.8.3 Combine the filtrates, acidify with HCl and evaporate to about 150 mL. Add 10 mL of diammonium phosphate [$(NH_4)_2HPO_4$, 250 g/L] and cool the solution in ice water. While stirring constantly, add NH_4OH drop by drop until the crystalline magnesium ammonium phosphate ($MgNH_4PO_4.6H_2O$) begins to form. Add NH_4OH in excess (5—10% by volume of the solution). Continue stirring for several minutes. Set aside in a cool place for at least 8 h. Filter, and redissolve the precipitate obtained in hot HCl (1:4), and dilute to about 100 mL. Add 1 mL of $(NH_4)_2HPO_4$ (250 g/L) and reprecipitate as described above. Set aside in a cool place for 2 h. Filter and wash 5 times with small portions of NH_4NO_3 wash solution. Place the filter paper and contents in a tared porcelain or silica crucible. Slowly char and ash the filter paper without inflaming, and ignite to constant mass at a temperature of 1050 ± 50°C.

6.3.8.4 Make a blank determination following the same procedure and using the same amounts of reagents. Correct the mass of ignited precipitate obtained in Clause 6.3.8.3 accordingly.

6.3.8.5 Calculate the percentage of MgO by multiplying

the corrected mass of magnesium pyrophosphate ($Mg_2P_2O_7$) by 72.4.

7. Methods for Physical Tests

7.1 General Requirements and Apparatus. The temperature and humidity of the physical test laboratory, the conditions of moist curing and water curing, and the apparatus required to perform the physical tests shall conform to the requirements of the appropriate Clause listed in Table 5.

7.2 Index to Physical Tests. Physical testing shall be performed in accordance with the appropriate Clause listed in Table 6.

7.3 Powder Tests

7.3.1 Determination of Fineness

7.3.1.1 Cement Fineness by Wet-Sieving

7.3.1.1.1 Equipment. The following equipment shall be used:

(a) Pressure gauge (see Clause 8.4.14.1);

(b) 45-µm sieve (see Clause 8.4.14.2);

(c) Spray nozzle (see Clause 8.4.14.3).

7.3.1.1.2 Procedure. Place 1.000 g of the cement on the clean, dry 45-µm sieve. Wet the sample thoroughly with a gentle stream of water. Remove the sieve from under the nozzle and adjust the pressure on the spray nozzle to 70.0 ± 3.5 kPa. Place the sieve under the nozzle and wash the sample for 1 min, moving the sieve with a circular motion in a horizontal plane at the rate of one motion per second in the spray. The bottom of the spray nozzle should extend into the sieve about 10 mm. Immediately upon removing the sieve from the spray, rinse once with 50 mL of distilled or de-ionized water, using caution not to lose any of the residue, and then blot the lower surface gently upon a damp cloth. Dry the sieve and residue in an oven or over a hotplate (see Note 1), supporting the sieve in such a manner that air may pass freely beneath it. Cool the sieve, and then brush the residue from the sieve and weigh it on an analytical balance capable of reproducing results within 0.0005 g (see Note 2).

Notes:
(1) *Care should be taken not to heat the sieve hot enough to soften the solder.*
(2) *After 5 determinations the sieve should be dipped in dilute acetic acid (1 + 6) or dilute HCl (1 + 10) and immediately rinsed with distilled or de-ionized water to remove particles lodged in the meshes. After 100 determinations, the sieve should be recalibrated.*

7.3.1.1.3 Calibration. Place 1.000 g of the current lot of National Bureau of Standards standard sample No. 114 on the clean, dry 45-µm sieve and proceed in accordance with Clause 7.3.1.1.2. The sieve correction factor is the difference between the test residue obtained and the assigned residue value indicated by the electroformed sheet sieve fineness specified for the standard sample, expressed as a percentage of the test residue.

Note: *It should be observed that the sieve correction as specified is a factor to be multiplied by the residue obtained and that the amount to be added or subtracted from the residue in any given test is, therefore, proportional to the amount of residue.*

Example of Determination of Sieve Correction Factor:

Residue 45-µm sieve, Sample No. 114	*12.2%*
Residue for a 1-g sample	0.122 g
Residue on sieve being calibrated	0.093 g
Difference	= + 0.029 g

Correction factor = +0.029/0.093 × 100 = +31.2%

7.3.1.1.4 Calculation of Fineness. Calculate the fineness of the cement to the nearest 0.1% as follows:

$R_c = R_s \times (100 + C)$

$F = 100 - R_c$

where

F = fineness of the cement expressed as the corrected percentage passing the 45-µm sieve

R_c = corrected residue, per cent

R_s = residue from the sample retained on the 45-µm sieve, grams

C = sieve correction factor (determined as prescribed in Clause 7.3.1.1.3), which may be either plus or minus

Example:

Sieve correction factor, C	= *+ 31.2%*
Residue from sample being tested, R_s	= 0.088 g
Corrected residue, R_c	= *0.088 × (100 + 31.2) = 11.5%*
Corrected amount passing, F	= *100 - 11.5% = 88.5%*

7.3.1.2 Sand Gradation

7.3.1.2.1 General. The size gradation requirements of Graded Sand and Standard Sand are respectively stipulated in Table 11 and Clause 8.5.3.3.

7.3.1.2.2 Equipment. The sieves used in checking the Graded Sand and Standard Sand shall meet the requirements specified in Clause 8.4.7.

7.3.1.2.3 Sampling Procedure. The samples selected for the acceptance test shall be obtained by repeated quartering of the entire contents of the 25-kg bag of graded sand, until portions of approximately 780 g are obtained; 780-g samples of both Graded Sand and Standard Sand are required for testing. The sand shall be thoroughly mixed and the pile flattened and spread out to minimize segregation during quartering.

Sample splitters may be used, provided that they are of suitable design to permit acquisition of sub-samples with gradation characteristics identical to those of the head sample.

7.3.1.2.4 Procedure. Five 100-g samples are needed to test the Graded Sand and 3 are required for the Standard Sand. These are obtained by 1 final quartering of the 780-g samples and by randomly selecting the necessary number of representative 100-g portions for test. The sieves shall be thoroughly clean and dry. The sand shall be placed on the sieve, which shall be held in one hand in a slightly inclined position so that the sample will be well

distributed over the sieve, the side being at the same time gently struck about 150 times/min against the palm of the other hand on the upstroke. The sieve shall be turned every 20—25 strokes about 1/6 of a revolution in the same direction. The operation shall continue until not more than 0.5 g passes through in 1 min of continuous sieving.

Mechanical sieving such as sieve shakers or vacuum-operated devices may be used, but hand-sieving shall constitute the referee method.

7.3.1.2.5 Calculation. The mass of residue retained on the sieve shall be expressed as a percentage of the mass of the original sample.

7.4 Paste Tests

7.4.1 Mixing Cement Pastes

7.4.1.1 Equipment. The apparatus used for mixing cement pastes shall conform to the following requirements:

(a) Scale (see Clause 8.4.13.2);

(b) Weights (see Clause 8.4.13.3);

(c) Mixer and Accessories (see Clause 8.4.5).

7.4.1.2 Procedure

7.4.1.2.1 A 650-g sample of dry cement shall be mixed with a measured amount of water in a mechanical mixer in accordance with Clause 7.4.1.2.2.

7.4.1.2.2 The dry paddle and the dry bowl shall be placed in the mixing position in the mixer. The materials for a batch shall then be introduced into the bowl and mixed in the following manner:

(a) Place all the mixing water in the bowl;

(b) Add the cement to the water and allow 30 s for the absorption of the water;

(c) Start the mixer and mix at slow speed (140 ± 5 r/min) for 30 s;

(d) Stop the mixer for 15 s and during this time scrape down into the batch any paste that may have collected on the sides of the bowl; and

(e) Start the mixer at medium speed (285 ± 10 r/min) and mix for 1 min.

7.4.2 Determination of Normal Consistency

7.4.2.1 Equipment. The apparatus used for determination of normal consistency of the paste shall conform to the requirements of Clause 8.4.10.1.

7.4.2.2 Manipulation. Cement paste, prepared as described in Clause 7.4.1.2, shall be quickly formed into a ball with the gloved hands and tossed a total of 6 times from one hand to the other, the hands being maintained about 150 mm apart. The ball, resting in the palm of the hand, shall be pressed into the larger end of the conical ring held in the other hand, completely filling the ring with paste. The excess at the larger end shall be removed by a single movement of the palm of the hand. The ring shall then be placed on its larger end on a glass plate and the excess at the smaller end sliced off at the top of the ring by 2 oblique strokes, in opposite directions, of a sharp-edged trowel held at a slight angle with the top of the ring. If necessary, the top surface shall be smoothed by not more than 2 light strokes of the trowel. During these operations care shall be taken not to compress the paste. The paste confined in the ring, resting on the plate, shall be placed under the rod and the larger end (C) shall be brought into contact with the surface of the paste and the set screw tightened; the scale shall then be read and the rod released 30 s after completion of mixing. The portion of the plunger coming into contact with the cement paste shall be kept clean and the apparatus shall be free from all vibration during the test.

7.4.2.3 Normal Consistency. The paste shall be of normal consistency when the rod settles to a point 10 ± 1 mm below the original surface 30 s after being released. Trial pastes shall be made with varying percentages of water until normal consistency is obtained. Each trial shall be made with fresh cement. The amount of water required for normal consistency shall be calculated as a percentage by mass of the dry cement. The cement test specimen used for normal consistency may be used for the determination of Vicat setting time.

7.4.3 Determination of Setting Time—Vicat Method

7.4.3.1 Equipment. The apparatus used for determination of setting time shall conform to the requirements of Clause 8.4.10.1.

7.4.3.2 Preparation. Cement paste of normal consistency shall be prepared as described in Clause 7.4.2 and immediately moulded into the ring G of the Vicat apparatus by the method given in Clause 7.4.2.2. Immediately after being moulded, the test specimen shall be placed in the moist closet or moist room and kept there except when the determinations of setting time are being made. The test specimens shall remain in the conical mould, supported by the plate H, throughout the test period. A setting time specimen and an autoclave bar may be made from the same batch.

7.4.3.3 Manipulation. At suitable intervals, the test specimen shall be placed in the Vicat apparatus under the rod B, the needle end of which (1-mm diameter) shall be carefully brought into contact with the surface of the paste and the set screw tightened; the scale shall then be read and the rod quickly released by a turn of the set screw. The portion of the plunger coming into contact with the cement paste shall be kept clean and the apparatus shall be free from vibration during the test.

7.4.3.4 Setting Time. The setting time, which shall be calculated beginning immediately after the addition of mixing water to cement, shall be considered to have occurred when the needle penetration of 25 mm is obtained in 30 s after being released.

7.4.4 Determination of Soundness by Autoclave Expansion Test

7.4.4.1 Equipment. The apparatus used in the autoclave expansion test shall conform to the following requirements:

(a) Scale (see Clause 8.4.13.2);

(b) Mixer and Accessories (see Clause 8.4.5);

(c) Autoclave and Accessories (see Clause 8.4.1).

7.4.4.2 Test Specimen. The governing test specimen shall be a prism of 25 mm square cross-section and of 125 mm effective gauge length. Optional specimens made in moulds described in Table 8 may be used.

7.4.4.3 Preparation of Specimen Moulds. The specimen moulds shall be prepared in accordance with the requirements of Clause 8.4.1.6.

7.4.4.4 Mixing Cement Paste. The standard batch, consisting of 650 g of cement and sufficient water to give a paste of normal consistency according to Clause 7.4.2, shall be prepared and mixed in accordance with the procedure described in Clause 7.4.1.

7.4.4.5 Moulding Specimens. Immediately following preparation of the setting time specimen or completion of mixing, the test specimen shall be moulded into 2 approximately equal layers, each layer being compacted with the thumbs or forefingers by pressing the paste into the corners, around the gauge studs, and along the surface of the mould until a homogeneous specimen is obtained. The top layer shall be compacted and the paste cut off flush with the top of the mould with a thin-edged trowel, and the surface smoothed with a few strokes of the trowel. During the operations of mixing and moulding, the hands shall be protected with rubber gloves.

7.4.4.6 Storage of Test Specimens. After the mould has been filled, it shall be placed in the moist closet or moist room. The specimens shall be in the moulds in the moist enclosure for at least 20 h; if removed from the moulds before 24 h, they shall be kept in the moist closet or moist room until the time of testing.

7.4.4.7 Test Procedure

7.4.4.7.1 At 24 ± ½ h after moulding, the specimens shall be removed from the moist atmosphere, immediately measured for length by means of the length comparator, and placed in the autoclave at room temperature in a rack so that the 4 sides of each specimen will be exposed to saturated steam. The autoclave shall contain enough water to maintain an atmosphere of saturated steam vapour during the entire period of test.* Specimens shall be rotated slowly in the measuring instrument while the measurement of length is being made. The minimum reading of the dial shall be recorded if the rotation causes a change in the dial reading. Specimens shall be placed in the instrument with the same end up each time a length measurement is taken.

**Ordinarily, 7—10% of the volume of the autoclave should be occupied by the water.*

7.4.4.7.2 To permit air to escape from the autoclave during the early portion of the heating period, the vent valve shall be left open until steam begins to escape.* Then the valve shall be closed and the temperature of the autoclave raised at a rate that will bring the gauge pressure of the steam to 2000 kPa in 45—75 min from the time the heat is turned on. Maintain the 2000 ± 70 kPa pressure for 3 h. At the end of the 3-h period, the heat supply shall be shut off and the autoclave cooled at such a rate that the pressure shall be less than 70 kPa at the end of 1½ h. At the end of the 1½-h period, any remaining pressure shall be slowly released by partially opening the vent valve until atmospheric pressure is attained. Then the autoclave shall be opened and the test specimen placed in water at a temperature above 90°C.

***Caution:** *See Safety Precautions, Notes (1) to (8), Clause 8.4.1.2.*

7.4.4.7.3 The water surrounding the bars shall be cooled at a uniform rate by adding cold water so that the temperature of the water will be lowered to 23°C in 15 min. The water surrounding the specimens shall be maintained at 23°C for an additional 15 min; then the specimens shall be surface-dried and their lengths measured again.

7.4.4.8 Calculations. The difference in the length of the test specimen before and after autoclaving shall be calculated to the nearest 0.01% of the effective length and shall be reported as the autoclave expansion of the cement. A contraction shall be indicated by prefixing a minus sign to the percentage expansion reported.

7.4.5 Determination of Heat of Hydration. The determination of the heat of hydration shall be in accordance with the requirements of ASTM Standard C186, Heat of Hydration of Hydraulic Cement. The heat of hydration determined in cal/g shall be converted to kJ/kg in the following manner:

Heat of Hydration kJ/kg = 4.1868 × cal/g

7.5 Mortar Tests

7.5.1 Mortar Mixing

7.5.1.1 Equipment and Material. The apparatus used for mixing cement mortars shall conform to the requirements of Clause 8.4.5.

7.5.1.2 Procedure

7.5.1.2.1 The materials and their proportions and quantities shall conform to the requirements contained in the particular method of test for which the mortar is being prepared.

7.5.1.2.2 The dry paddle and the dry bowl shall be placed in the mixing position in the mixer. The materials for a batch shall then be introduced into the bowl and mixed in the following manner:

(a) Place the water in the bowl;

(b) Add the cement to the water; then start the mixer and mix at the slow speed (140 ± 5 r/min) for 30 s;

(c) Add the entire quantity of sand slowly over a 30-s period while mixing at slow speed;

(d) Stop the mixer, change to medium speed (285 ± 10 r/min), and mix for 30 s;

(e) Stop the mixer and let the mortar stand for 1½ min. During the first 15 s of this interval, quickly scrape down into the batch any mortar that may have collected on the side of the bowl; then cover the bowl with the lid;

(f) Finish the mixing period for 1 min at medium speed (285 ± 10 r/min) after removing the cover;

(g) Where a fixed water:cement ratio and a 2-min delay period replace the determination of flow for acceptance testing of Portland cements as described in Clause 7.5.3.3.2, quickly scrape down any mortar that may have

collected on the bowl before covering. At the end of the delay period remove the cover and complete the mixing operation with a 15-s remix at medium speed (285 ± 10 r/min);

(h) When the flow determination is required, return the mortar used for the flow test to the bowl and remix for 15 s at medium speed (285 ± 10 r/min);

(i) To terminate the mixing operation quickly scrape any mortar adhering to the side of the bowl upon completion of the final 15-s remix period into the batch.

7.5.2 Determination of Mortar Flow

7.5.2.1 Equipment and Materials. The apparatus used for the determination of mortar flow shall conform to the requirements of Clause 8.4.3.

7.5.2.2 Procedure

7.5.2.2.1 The flow table shall be carefully wiped dry and the flow mould placed at the centre. Upon completion of mixing, according to Clause 7.5.1, the excess mortar shall be shaken from the paddle into the bowl. A layer of mortar about 25 mm in thickness shall be placed in the mould and tamped 20 times with the tamper (see Clause 8.4.8). The tamping pressure shall be just sufficient to ensure uniform filling of the mould. The mould shall then be filled with mortar tamped as specified for the first layer. The mortar shall be cut off to a plane surface, flush with the top of the mould, by drawing the straight-edge of a trowel (held nearly perpendicular to the mould) with a sawing motion across the top of the mould. The table-top shall be wiped clean and dry, extra care being taken to remove any water from around the edge of the flow mould. The mould shall be lifted away from the mortar 60 s after completing the mixing operation. The table shall immediately be dropped through a height of 12.5 mm 25 times in 15 s.

7.5.2.2.2 The flow is the resulting increase in the average diameter of the mortar mass measured on 4 diameters at 45° intervals and expressed as a percentage of the original diameter. Trial mortar shall be made with varying percentages of water until the specified flow is obtained. Each trial shall be made with fresh mortar.

7.5.3 Compressive Strength

7.5.3.1 Equipment and Materials. The apparatus and materials used for the determination of compressive strength shall conform to the following requirements:

(a) Compression Test Equipment (see Clause 8.4.2);

(b) Graded Sand (see Clause 8.5.3.2).

7.5.3.2 Test Pieces. The test pieces shall be 50 mm cubes prepared and tested with the apparatus and methods outlined in Clauses 7.5.3.1 to 7.5.3.8 inclusive.

7.5.3.3 Proportioning and Mixing Mortars

7.5.3.3.1 Mix Proportions. The proportions of the standard mortar shall be 1 part cement to 2.75 parts Graded Sand by mass. The quantities of dry materials to be mixed at one time in the batch or mortar for making 9 cubes shall be 740 g of cement and 2035 g of Graded Sand. (For 6 cubes 500 g of cement and 1375 g of Graded Sand shall be used.)

7.5.3.3.2 Consistency. For acceptance testing of Portland cements, fixed water:cement ratios of 0.485 shall be used for Normal and Moderate cements and 0.470 for Low Heat of Hydration and Sulphate Resistant cements; the flow test shall be omitted and the mortar allowed to stand in the covered mixing bowl for 2 min. It shall then be remixed for 15 s at medium speed before the moulding of specimens is proceeded with, as described in Clause 7.5.3.4.1.

For High Early Strength cement, the amount of mixing water, measured in millilitres, shall be such as to produce a flow between 100 and 115%, as determined in accordance with the procedure specified in Clause 7.5.2, and shall be expressed as a percentage by mass of cement.

7.5.3.3.3 Mixing Procedure. The mortar shall be mixed in accordance with the requirements of Clause 7.5.1.

7.5.3.4 Moulding Test Specimens

7.5.3.4.1 Filling of Moulds. Immediately following completion of the flow test, the mortar from the flow mould shall be returned to the mixing bowl.* Any mortar that may have collected on the side of the bowl shall be quickly scraped down into the batch and the entire batch shall be given a 15-s mixing at medium speed. Within a total elapsed time of not more than 2 min and 30 s after completion of the original mixing of the mortar batch, moulding of the cubes shall be started. A layer of mortar about 25 mm in thickness shall be placed in all of the cube compartments; then the mortar in each cube compartment shall be tamped with the tamper (see Clause 8.4.8) 32 times in about 10 s in 4 rounds, each round to be at right angles to the other and consisting of 8 adjoining strokes over the surface of the specimen, as illustrated in Figure 1.

**For acceptance testing of cement mortars with fixed water:cement ratios the flow test shall be omitted in accordance with the procedure specified in Clause 7.5.3.3.2. However, changes in the properties of the cement as well as the size gradation characteristics of the Graded Sand are reflected in mortar consistency and it is advisable to periodically monitor the flow when preparing mortars with fixed water:cement ratios. If additional specimens of other types of cement are immediately required, the flow test may be omitted for identical batches of mortar, provided that there is no reason to doubt that the mortar produced in subsequent batches is of comparable consistency. In all cases where the flow test is omitted, the mortar shall stand in the covered mixing bowl for 2 min and then be remixed at medium speed for 15 s before the moulding of specimens is proceeded with.*

7.5.3.4.2 Tamping and Finishing. The tamping pressure shall be just sufficient to ensure uniform filling of the moulds. The 4 rounds of tamping (32 strokes) of the mortar shall be completed in 1 cube before going to the next. When the tamping of the first layer in all of the cube compartments is complete, the compartments shall be filled with the remaining mortar and then tamped as specified for the first layer. During the tamping of the second layer the mortar forced out onto the tops of the moulds shall be brought in after each round of tamping by means of the gloved fingers and tamper. On completion of the tamping, the tops of all cubes should extend slightly above the tops of the moulds. The mortar that has been forced out onto the tops of the moulds shall be brought in

with a trowel and the cubes smoothed off by drawing the flat side of the trowel (with the leading edge slightly raised) once across the top of each cube at right angles to the length of the mould. Level the mortar protruding above the top of the mould by lightly drawing the flat side of the trowel (with the leading edge slightly raised) once along the length of the mould. The mortar shall then be cut off to a plane surface flush with the top of the mould by drawing the straight-edge of the trowel (held nearly perpendicular to the mould) with a sawing motion over the length of the mould. The process of forming the cube specimens shall continue to completion without delay following the mixing operation.

7.5.3.4.3 Storage of Test Specimens. All test specimens, immediately after moulding, shall be kept in the moulds on the base plates in the moist closet or moist room for 20—24 h* with their upper surfaces exposed to the moist air but protected from dripping water. If removed from the moulds before 24 h, they shall be kept on the shelves of the moist closet or moist room until they are 24 h old, when the specimens, except those for the 24-h test, shall be immersed in the water of the storage tanks or cabinets.

**Except in the case of dispute, a demoulding period of* 20—72 h *is permitted.*

7.5.3.5 Testing

7.5.3.5.1 Test Period. All test specimens for a given test age shall be broken within the permissible tolerance prescribed as follows:

Test Age	Permissible Tolerance
24 h	± ½ h
3 d	± 1 h
7 d	± 3 h
28 d	± 12 h

If more than 1 specimen at a time is removed from the moist closet for the 24-h tests, these specimens shall be kept covered with a damp cloth until the time of testing. If more than 1 specimen at a time is removed from the storage water for testing, these specimens shall be kept in water at a temperature of 23 ± 1.5°C and of sufficient depth to completely immerse each specimen until the time of testing.

7.5.3.5.2 Preparation of Specimen Face. Each cube shall be wiped to a surface-dry condition and any loose sand grains or incrustations shall be removed from the faces that will be in contact with the bearing blocks of the testing machine. These faces shall be checked by the application of a straight-edge.* If appreciable curvature is present, the face or faces shall be ground to plane surfaces or the specimens shall be discarded.

**The concave form of planeness variation referred to in Clause 8.4.2.2 should be restricted to less than* 0.025 mm *if a high degree of accuracy is to be achieved. The cubes should also be free of surface blemishes or particles that could alter the effective application of load over the surface of the specimen.*

7.5.3.6 Application of Load. The load shall be applied to the cube faces that were in contact with the true plane surface of the mould (see Note). The cube shall be carefully placed in the testing machine below the centre of the upper bearing block, so that it will occupy a central position in relation to the upper bearing platen. It shall be ascertained that the spherically seated block is free to tilt prior to testing each cube. No cushioning or bedding material shall be used. The specimen shall be uniformly loaded without interruption to failure at a rate of 25 ± 5 MPa/min. No adjustment shall be made to the controls of the compression machine while the specimen is yielding rapidly before failure.

Note: *It will be found helpful to identify individual cube faces for the specimens produced from each compartment of all moulds so that the cubes may always be located between the bearing blocks of the compression machine in exactly the same position relative to their formation. It is advisable to then determine the rank order of all specimens produced from all moulds in use by conducting a carefully controlled comparative study using a fixed amount of water for the preparation of the test mortar. The uniformity of the cement and standard sand mix constituents must be assured by exacting blending and/or splitting techniques and the relative nature of the various test requirements must be firmly established. The data obtained from such a test program will permit the formation of near identical mould series for the routine test periods that will markedly assist in assuring the relative nature of all subsequent test data.*

7.5.3.7 Presentation of Data. The total maximum load indicated shall be recorded and the compressive strength expressed in megapascals (MPa) rounded off to the nearest 0.1 MPa. If the cross-sectional area of the cube varies from 2500 mm² by more than 40 mm², the actual area shall be used for the calculation of the compressive strength.

7.5.3.8 Retest Cubes that are manifestly faulty, or that give strengths differing more than 10% from the average value of all test specimens made from the same sample and tested at the same period, shall not be considered in determining the compressive strength.

Note: *If all specified requirements and procedures are carefully controlled, the maximum variation between the 3 cubes produced from a single mould should not exceed* 0.7 MPa. *Differences greater than this amount indicate faulty facilities or techniques.*

7.5.4 Sulphate Resistance

7.5.4.1 Equipment and Materials. The apparatus and materials used shall conform to the following requirements:

(a) Bar Moulds (see Clause 8.4.1.6);

(b) Graded Sand (see Clause 8.5.3.2);

(c) Gypsum for Sulphate Resistance Tests (see Clause 8.5.2);

(d) Length Comparator (see Clause 8.4.1.5).

7.5.4.2 Test Pieces. Test pieces shall be 25 mm × 25 mm × 160 mm, each having a 125-mm effective gauge length, or 25 mm × 25 mm × 285 mm, each having a 250-mm effective gauge length.

7.5.4.3 Number of Specimens. Six test specimens shall be made for each cement.

7.5.4.4 Mould Preparation. The interior surfaces of the

mould shall be covered with a concrete form oil.* The gauge studs shall then be set, care being taken to keep them clean and free of oil. Beeswax or paraffin wax heated to the melting point, or a mixture of 3 parts of paraffin wax to 5 parts of rosin by mass, heated between 100°C and 120°C, shall be applied to the outside contact lines of the mould to make the mould watertight.

**A form oil will be acceptable if it serves as a parting agent without affecting the setting of the cement and without leaving any residue that will inhibit the penetration of water into the specimen.*

7.5.4.5 Mortar Preparation

7.5.4.5.1 Proportions. The quantities of dry materials required for each batch shall be 400 g of cement (including added gypsum) and 1100 g of Graded Sand. The percentage of cement and gypsum required to provide a mixture containing 7% SO_3 shall be calculated by mass as follows:

(a) Cement, per cent $= \frac{g - 7.0}{g - c} \times 100$

(b) Gypsum, per cent $= \frac{7.0 - c}{g - c} \times 100$

where

c = SO_3 content of Portland cement, per cent

g = SO_3 content of gypsum, per cent

7.0 = SO_3 content of cement-gypsum mixture, per cent

7.5.4.5.2 Flow. The amount of mixing water (distilled), measured in millilitres, shall be such as to produce a flow between 100 and 115% as determined in accordance with Clause 7.5.2.

7.5.4.5.3 Mixing. The mortar shall be mixed in accordance with the requirements of Clause 7.5.1, except that the gypsum shall be added to the water in the bowl and mixed at slow speed (140 ± 5 r/min) for 15 s. The mixer shall then be stopped and the cement added to the bowl. The method of mixing shall then proceed exactly as specified in Clause 7.5.1 following the addition of the cement.

7.5.4.6 Moulding Test Specimens. Immediately upon completion of the flow test, the mortar shall be returned to the bowl, any mortar on the side of the bowl scraped down into the batch, and the batch remixed at medium speed (285 ± 10 r/min) for 15 s. The paddle and the bowl shall be removed from the mixer and the excess mortar shaken from the paddle into the bowl. The mould shall be filled in 2 layers, each layer being compacted with the tamper. The mortar shall be worked into the corners, around the gauge studs, and along the surfaces of the mould with the tamper until a homogeneous specimen is obtained. After the top layer has been compacted, the mortar shall be cut off flush with the top of the mould and the surface smoothed with a few strokes of the trowel.

7.5.4.7 Storage of Test Specimens

7.5.4.7.1 Initial Storage. The specimens shall be cured in the moulds in the moist closet for 22—23 h. They shall then be removed from the moulds, properly identified, and placed in distilled water at 23 ± 1.5°C for at least 30 min prior to making the initial length measurement.

7.5.4.7.2 Subsequent Storage. After the bars have been removed from the moulds and measured, they shall be stored horizontally in distilled water at 23 ± 1.5°C. The specimens shall be stored with at least 6-mm clearance on all sides, supported on three equidistant 6-mm glass rods placed along the length of the bars. The specimens shall be covered with at least 12 mm of distilled water. The ratio of the volume of the water to the volume of the bars shall not exceed 5:1, to prevent excessive leaching. The water level shall be maintained by adding distilled water at the end of 7 days.*

**If, for information purposes, the test is extended beyond 14 days, the water level should be adjusted every 7 days.*

7.5.4.8 Length Measurement

7.5.4.8.1 Method. The specimens shall be measured for length by means of the length comparator. They shall be removed from the water storage, 1 at a time, and wiped with a damp cloth before measuring. Specimens shall be rotated slowly in the measuring instrument while the measurement of length is being made. The minimum reading of the dial shall be recorded if the rotation causes a change in the dial reading. Specimens shall be placed in the instrument with the same end up each time a length measurement is taken.

7.5.4.8.2 Frequency. The first reading shall be made at the age of 24 h ± 15 min from the time the cement and water are mixed together. The specimens shall again be measured at the age of 14 days.*

**If, for information purposes, the test is extended beyond 14 days, the specimens should be returned to water for storage immediately after measurement for additional measurements at later ages, for example,* 28 d, 56 d, *etc.*

7.5.4.9 Calculation. The difference in length of the specimen at 24 h and at 14 d shall be calculated to the nearest 0.001% of the effective gauge length and shall be reported as the expansion of the specimen at that period.

7.5.5 Sulphate Expansion

7.5.5.1 General. The method of test, the equipment, and the materials required for the sulphate expansion test are as described in Clauses 7.5.4.1 to 7.5.4.9 inclusive, with the exception of Clauses 7.5.4.1(c) and 7.5.4.5. The method of mortar preparation for the sulphate expansion test, without the further addition of gypsum, shall be according to Clause 7.5.5.2.

7.5.5.2 Mortar Preparation

7.5.5.2.1 Proportions. The quantities of dry materials required for each batch shall be 400 g of cement and 1100 g of Graded Sand.

7.5.5.2.2 Flow. The amount of distilled mixing water measured in millilitres shall be such as to produce a flow between 100 and 115% as determined in accordance with Clause 7.5.2.

7.5.5.2.3 Mixing. The mortar shall be mixed in accordance with the requirements of Clause 7.5.1.

8. Equipment and Materials

8.1 General. This Clause specifies the temperature and humidity requirements of the physical test laboratory and the conditions established for the moist curing and water storage units. It also contains a list of all testing equipment, with attendant specifications, required to conduct all of the chemical and physical determinations covered by this Standard.

Test equipment manufactured to metric standards shall be used, if commercially available. However, existing equipment conforming to the Imperial standards, or test equipment not available in metric version may be used, provided that such equipment conforms to the requirements of Clause 8 of CSA Standard A5-1971 and Supplement No. 1-1977 (withdrawn).

The materials used for the tests are also listed and their requirements are similarly defined.

8.2 Equipment and Materials. Equipment and materials shall conform to the requirements of the appropriate Clause listed in Table 7.

8.3 Conditions

8.3.1 Room. The temperature of the cement testing laboratory, mixing table, and apparatus shall be maintained at 23 ± 3°C. The relative humidity shall be not less than 50%.*

**A maximum of 65% is desirable.*

8.3.2 Humidity Cabinet. The temperature of the moist closet and moist room shall be 23 ± 1.5°C and the relative humidity not less than 95%.

Note: *The method employed to maintain the required humidity should not cause water to fall on the surface of freshly moulded specimens. It is desirable to have a separate compartment for setting time test specimens. They require frequent checking and the opening and closing of doors may adversely affect other tests. Specimens in storage should both look and feel moist. The shelves on which freshly moulded specimens are placed should be level.*

8.3.3 Water Storage. The temperature of the water in the storage tanks shall be 23 ± 1.5°C. A temperature control system for cooling and heating is necessary at most locations.

Notes:
(1) *A means for circulating the water is also required for large vessels and a recording thermometer should be used to provide a continuous record of the temperature of the water.*
(2) *Only non-corroding material should be used in the construction of the tanks and racks or trays that may be employed in storage units. Tanks should be enclosed to control cooling of the storage water due to evaporation as well as to minimize the humidifying effect upon the air of the laboratory.*
(3) *Fresh water should not be added directly to the storage, since it results in the leaching of soluble salts from the specimens and adversely affects their physical properties. Any replacement water required when the tanks are cleaned, or make-up water needed to compensate for loss due to evaporation, should be saturated with lime and adjusted to conform to the temperature requirements of this Standard. The tanks should be kept clean by periodically removing any residues or incrustation formed on the interior or contents. A false bottom consisting of Nalgene mesh or similar noncorrosive material may be used effectively to collect and contain fine residues at the base of the tank.*
(4) *Test specimens containing materials possessing accelerating or retarding effects should not be placed in the same storage water as other test specimens. They may be placed in separate trays located in the humidity cabinet. They could also be stored in sealed plastic bags containing sufficient lime-saturated water to completely immerse the specimens, and then located in the water storage tank in order to establish the curing temperature requirements.*

8.4 Equipment

8.4.1 Autoclave

8.4.1.1 General. The autoclave shall meet the applicable requirements of CSA Standard B51, Code for the Construction and Inspection of Boilers and Pressure Vessels.

8.4.1.2 Vessel and Control. The autoclave shall consist of a high-pressure steam vessel provided with a thermometer well. The autoclave shall be equipped with an automatic pressure control and a rupture disc with a bursting pressure of 2.4 MPa ± 5%. In locations where the use of a rupture disc is not permitted, the autoclave shall be equipped with a safety valve (see Clause 8.4.1.1). In addition, the autoclave shall be equipped with a vent valve to allow the escape of air during the early part of the heating period and to release any steam pressure remaining at the end of the cooling period. The pressure gauge shall have a dial with a nominal diameter of 110 mm and shall be graduated from 0 to 4.0 MPa with scale divisions of not more than 25 kPa. The error in the gauge shall not exceed ± 20 kPa at the operating pressure of 2000 kPa. The capacity of the heating unit shall be such that with maximum load (water plus specimens) the pressure of the saturated steam in the autoclave may be raised to a gauge pressure of 2000 kPa in 45—75 min from the time the heat is turned on. The automatic pressure control shall be capable of maintaining the gauge pressure at 2000 ± 70 kPa for at least 3 h. A gauge pressure of 2000 ± 70 kPa corresponds to a temperature of 216 ± 2°C. The autoclave shall be designed to permit the gauge pressure to drop from 2000 kPa to less than 70 kPa in 1½ h after the heat supply has been shut off.

Notes on Safety Precautions:
(1) *The pressure gauge should have a maximum capacity of 4000 kPa. This is important because with too small capacity there is but little length of arc in which the gauge hand may indicate pressures above the specified maximum working pressure. The operator must be sure the gauge hand has not passed the maximum graduation on the scale.*
(2) *It is well to have the pressure gauge tested, but in any event always use a thermometer together with the pressure gauge so as to provide a means of detecting any failure of the pressure gauge to operate properly, and to indicate any unusual condition.*
(3) *The automatic control should be maintained in proper working order at all times.*
(4) *The safety valve should be set to relieve the pressure at about 6—10% above the maximum of 2100 kPa specified in this method of test; that is, at about 2275 kPa. Unless the manufacturer has given specific instructions*

as to maintenance of the safety valve, the valve should be tested twice a year. It can be tested either with a gauge testing device or by adjusting the automatic controls to allow the autoclave to reach a pressure of about 2275 kPa, at which pressure the safety valve should either open or be adjusted to open. The safety valve discharge should be directed away from the operator.

(5) *Unexpected combinations of conditions may occur. For example, in one case the automatic control had failed, the safety valve had become stuck, and the gauge hand, which at first glance appeared to be at about zero, had passed the maximum graduation and had come to stop on the wrong side of the pin. This condition of the gauge was finally detected and the pressure, then of an unknown magnitude, was released before failure could occur in the apparatus.*

(6) *Heavy, leather work gloves should be worn to prevent burning of the hands when removing the top of the autoclave at the end of the test. The vent valve should be directed away from the operator. When removing the autoclave lid, it should be tilted so that any steam escaping from beneath the lid may be discharged away from the operator. Care should be taken to avoid scalding.*

(7) *It should be remembered that for many of the autoclave pressure gauges now in use the return of the gauge hand to the initial rest or starting point does not necessarily indicate zero pressure within the autoclaves; there may then still remain an appreciable pressure.*

(8) *Good maintenance practices on the autoclave will contribute to safer operation. Some suitable graphite lubricant should be added on the bolt threads to lessen wear and facilitate the tightening of the autoclave top. In order to prevent rusting, the water should be removed after every test and the autoclave should be wiped dry. In order to protect the pressure gauge, regulator, and safety valve from direct contact with high-pressure steam, the pipe connections (visible outside the autoclave) should be filled as completely as possible prior to starting the test by pouring distilled water with a syringe through the* 6 mm *hole inside the pressure chamber. Periodic inspections should be made to detect any plugging of pipe from chamber to pressure regulator, which might interfere with proper control.*

8.4.1.3 Rupture Disc. The rupture disc shall be made of a material having a tensile strength that is relatively insensitive to temperature in the range of 20—216°C and that is electrochemically compatible with the pipe leading to it and to its holder.

8.4.1.4 Thermometer. The thermometer shall conform to ASTM Standard E1, ASTM Thermometers, and shall be a No. 2C with a range of -5 to +300°C. It shall be of the partial immersion type, with wide bore and fused-in graduations.

8.4.1.5 Length Comparator

8.4.1.5.1 The comparator for measuring length change of specimens shall be designed to accommodate the size of specimen employed and to provide or permit a positive means of contact with the gauge studs and convenient and rapid measurement of lengths of specimens.

8.4.1.5.2 The comparator for measuring length changes of specimens produced in the Types F and M moulds shall provide a high-grade dial micrometer or other measuring device graduated to read in 0.001-mm or 0.002-mm units, accurate within 0.002 mm in any 0.020-mm range, and within 0.004 mm in any 0.200-mm range, and a range of at least 8.0 mm in the measuring device to allow for small variations in the gauge length of various specimens.*

**It is recommended that the micrometer or other measuring device be calibrated throughout its range to determine both periodic and cumulative errors for proper correction of observed data.*

8.4.1.5.3 The design shall provide a means for checking the measuring device at regular intervals against a reference bar. (See Clauses 8.4.1.5.4 and 8.4.1.5.5.)

8.4.1.5.4 The reference bar that serves as a standard for the gauge dial setting shall have an overall length of 300 ± 1.5 mm or 170 ± 1.5 mm, whichever is appropriate for the specimen in use. The bar shall be of a steel alloy having a coefficient of thermal expansion not greater than 2×10^{-6}/K. Each end shall be machined to the same shape as the contact end of a gauge stud, and shall be heat treated, hardened, and then polished. The central 100 mm of the length of the reference bar shall be covered by a rubber tube with a wall at least 3 mm thick to minimize the effect of temperature change during handling. The reference bar shall be provided near one end with a positioning mark, and shall be placed in the instrument in the same position each time a length measurement is taken.

8.4.1.5.5 The dial gauge setting of the measuring device shall be checked by use of the reference bar at least at the beginning and end of the readings made within ½ day when the apparatus is kept in a room maintained at constant temperature. It shall be checked more often when kept in a room where the temperature is not constant.

8.4.1.6 Bar Moulds

8.4.1.6.1 Description. Moulds shall have either 1 or 2 compartments. The moulds and the test specimens shall conform to the respective dimensional requirements set out in Table 8. In case of dispute, results obtained with specimens made in Type F moulds shall govern. The effective gauge length shall be considered as the length between the innermost ends of the stainless steel gauge studs. The parts of the moulds shall be tight fitting and firmly held together when assembled, and their surfaces shall be smooth and free of pits. The moulds shall be made of steel or other hard metal not readily attacked by the cement paste, mortar, or concrete. The sides of the moulds shall be sufficiently rigid to prevent spreading or warping. Each end plate of the mould shall be equipped to hold a knurled gauge stud properly in place during the setting period. The gauge studs shall be of AISI* Type 316 stainless steel or the equivalent. To prevent restraint of the gauge studs during initial shrinkage of the specimen, the device for holding the gauge studs in position shall be so arranged that, if necessary, it can be partially or completely released after the compaction of the paste or mortar into place in the mould. The gauge studs shall be set so that their principal axes coincide with the principal axis of the test specimen.

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8.4.1.6.2 Assembly and Lubrication. Prior to moulding specimens, the outside joints of the mould and the contact lines of the moulds and base plates shall be sealed with a microcrystalline wax. The interior surface of the

mould shall be thinly covered with a mineral oil. After this operation, the stainless steel gauge studs shall be set, care being taken to keep them clean and free of oil, grease, and foreign matter.

8.4.1.7 Steam Bath

8.4.1.7.1 The steam bath shall be designed to have a rack to support the specimens in such a manner that water is not in contact with the specimens to be tested. A sloping cover shall be provided above the specimens to prevent condensed steam from dripping onto the surface of the specimens. Bars may be supported in either the vertical or horizontal position. If in the horizontal position, they shall be supported on 10-mm rods placed 100 mm on centre.

8.4.1.7.2 The bath shall be properly vented so that the pressure does not rise above atmospheric pressure. Provision shall be made for a sufficient water supply.

8.4.2 Compression Test Equipment

8.4.2.1 Compression Machine. The testing machine shall be either the hydraulic or the screw type with sufficient opening between the upper bearing surface and the lower bearing surface of the machine to permit the use of verifying apparatus. The load applied to the test specimen shall be indicated with an accuracy of ± 1.0%. The upper bearing shall be a spherically seated, hardened metal block firmly attached at the centre of the upper head of the machine. The centre of the sphere shall lie at the centre of the surface of the block in contact with the specimen. The block shall be closely held in its spherical seat, but shall be free to turn in any direction.* The diagonal or diameter of the bearing surface shall be only slightly greater than the diagonal of the face of the 50-mm cube in order to facilitate accurate centering of the specimen, unless a centering device is employed that ensures the required location of the cube. A hardened metal bearing block shall be used beneath the specimen to minimize wear of the lower platen of the machine. The bearing block surfaces intended for contact with the specimen shall have a Rockwell hardness number not less than C60. These surfaces shall not depart from plane surfaces by more than 0.0125 mm when the blocks are new and shall be maintained within a permissible variation of 0.025 mm.

**Grease should not be used to lubricate the spherical seat of the upper bearing block; use only a very light coating of a good quality, thin grade lubricant to the joint of the upper platen. Formation of the characteristic "hour glass" pattern after fracture confirms the effective centering of specimens and uniform application of load. Oblique fractures may be associated with low results.*

8.4.2.2 Cube Moulds. Cube moulds shall be made of acid resistant stainless steel with sides sufficiently rigid to prevent spreading or warping when in use and shall conform to the following Items (a) to (e). The continued use of existing moulds made of other materials is permitted, provided they continue to meet the requirements of Items (a) to (e) following:

(a) The interior faces of the moulds shall be plane surfaces with a permissible variation of 0.025 mm;

(b) The distance between opposite faces shall be 50 mm with a permissible variation of ± 0.25%;

(c) The height of the moulds, measured separately for each cube compartment, shall be 50 mm with a permissible variation of ± 0.25%;

(d) The tolerances for planeness, distance between opposite faces, and height are doubled for used moulds*; and

(e) The angle between adjacent interior faces and between interior faces and top and bottom planes of the mould shall be 90 ± 0.5° measured at points slightly removed from the intersection of the faces.

**Wear on the mould caused by tamping and poor cleaning methods results in specimens with surfaces that are not plane. An ultrasonic cleaning system including the use of sulphamic acid may help prevent this wear. Tools used in the cleaning process should be softer than the mould; their use should be kept to a minimum and restricted to those parts of the mould not affected by the dimensional tolerances of this Standard. The interior faces of the mould should be cleaned with cloths only.*

Note: *It is possible to obtain improved closure of mould halves by periodically correcting any distortion that may occur through careful application of pressure to the sides of the mould by means of a vise. This should be done prior to securing the mould to the base plate in a way that will not produce twisting or warping of the assembly.*

8.4.2.3 Base Plates. The mould shall be firmly secured to a plate that covers the entire area of the underside of the mould. The base plate shall have a plane surface with variation not greater than 0.05 mm. It shall be at least 10 mm thick so that it will provide for maintenance of surface planeness while imparting rigidity to the entire mould assembly. Two pins mounted normal to the plane of the base plate shall be used to secure the mould to the base plate. The pins shall be threaded at the free end and furnished with wing nuts and washers. They shall be positioned to provide a firm and uniform union of the mould to the base plate without imparting distortion to the mould sections. The spacing between the base plate and the mould, when secured, shall be not greater than 0.10 mm measured by feeler gauge*. The specification on spacing shall also apply to the contact areas between mould sections.

**Enlarged spacing between the mould and base plate may be corrected by repositioning the pins on the opposite side of the base plate.*

8.4.2.4 Mould Assembly and Lubrication. A mineral oil, or any substance that will provide a clean separation of the specimen and not adversely affect the development of strength within the specimen, shall be wiped on the mould. The separating agent shall be applied in a way that will provide a thin and total cover over the interior faces of the mould halves and base plate. Any excess oil collecting at the base of the mould prior to use shall be removed. Watertight joints shall be obtained through the application of paraffin wax to the exterior contact lines of the mould halves and mould and base plate.* The mould shall be carefully examined to ensure that there is no loss of water or paste following the moulding operation. If this occurs, the specimens shall be discarded and the technique of sealing improved.

**Microcrystalline wax is very effective for sealing moulds. A 3-part paraffin wax and 5-part rosin mix heated to between 100 and 120°C may be used but is found difficult to remove. If leakage from the mould occurs during the*

forming operation, it may become necessary to coat adjoining surfaces of the assembly with petrolatum. If this practice is adopted, care must be exercised to remove any excess sealant that may penetrate the mould interior.

8.4.3 Flow Table

8.4.3.1 General

8.4.3.1.1 Table-Top and Frame. The flow table apparatus shall be constructed in accordance with the detailed design and dimensional requirements shown in Figure 2. The apparatus shall consist of an integrally cast rigid iron frame and a circular rigid table-top 254 ± 2.5 mm in diameter, with a shaft attached perpendicular to the table-top by means of a screw thread. The table-top, to which the shaft with its integral contact shoulder is attached, shall be mounted on a frame in such a manner that it can be raised and dropped vertically through a fixed height of 12.5 ± 0.125 mm for new tables and 12.5 ± 0.375 mm for tables in use, by means of a rotated cam. The table-top shall have a fine-machined plane surface, free of blow-holes and surface defects, and shall be scribed as shown in Figure 2. The table-top shall be of cast brass or bronze having a Rockwell hardness number not less than B25 with an edge thickness of 7.5 ± 1.25 mm and shall have 6 integral radial stiffening ribs. The table-top and attached shaft shall weigh 4.1 ± 0.05 kg and the mass shall be symmetrical around the centre of the shaft.

8.4.3.1.2 Cam and Shaft. The cam and vertical shaft shall be of medium carbon machinery steel, hardened where indicated in Figure 2. The shaft shall be straight and the difference between the diameter at the bearing sections of the shaft and the diameter of the bore of the frame shall be not less than 0.05 mm and not more than 0.075 mm for new tables or 0.25 mm for tables in use. The end of the shaft shall not fall upon the cam at the end of the drop, but shall make contact with the cam not less than 120° from the point of drop. The face of the cam shall be a smooth spiralled curve of uniformly increasing radius from 12.5 to 32 mm in 360°, and there shall be no perceptible jar as the shaft comes into contact with the cam. The cam shall be so located and the contact faces of the cam and shaft shall be such that the table does not rotate more than 1 revolution in 25 drops. The surfaces of the frame and of the table that come into contact at the end of the drop shall be plane and horizontal and parallel with the upper surfaces of the table and shall make continuous contact over a full 360°.

8.4.3.1.3 Supporting Frame and Drive. The supporting frame of the flow table shall be integrally cast of fine-grained, high-grade cast iron. The frame casting shall have 3 integral stiffening ribs extending the full height of the frame and located 120° apart. The top of the frame shall be chilled to a depth of approximately 6.0 mm and the face ground and lapped square with the bore and to give 360° contact with the shaft shoulder. The underside of the base of the frame shall be ground to secure a complete contact with the steel plate beneath. The flow table shall be driven by a motor*, connected to the cam shaft through an enclosed worm gear speed reducer and flexible coupling. The speed of the cam shaft shall be approximately 100 r/min. The mortar drive mechanism shall not be fastened or mounted on the table base plate or frame.

**A 35-W motor has been found adequate.*

8.4.3.1.4 Supporting Pedestal. The flow table frame shall be tightly bolted to a cast iron or steel plate at least 25 mm thick and 250 mm square. The top surface of this plate shall be machined to a smooth plane surface. The plate shall be anchored to the top of a concrete pedestal by 4 approximately 13-mm bolts or threaded rods made of mild steel that pass through the plate and are embedded at least 150 mm in the pedestal. The pedestal shall be cast inverted on the base plate so that positive contact will be obtained at all points between the pedestal and base plate. The pedestal shall be 250—280 mm square at the top, 380—400 mm at the bottom, and 650—750 mm in height. The pedestal shall have a mass of at least 135 kg. A stable gasket cork pad 12.5 mm thick and approximately 100 mm square shall be inserted under each corner of the pedestal.

8.4.3.1.5 Levelling and Stability. The table-top, after the frame has been mounted on the pedestal, shall be level along 2 diameters at right angles to each other, in both the raised and lowered positions. Levelling shall be achieved by suitable means under the base of the pedestal. The flow table shall be checked frequently for levelness of table-top, stability of pedestal, and tightness of bolts and nuts at the table base and pedestal. A torque of 27 N·m shall be used when tightening those fastenings. No nuts or other such levelling devices shall be used between the plate and the pedestal.

8.4.3.1.6 Lubrication. The vertical shaft of the table shall be kept clean and lightly lubricated with a light oil (SAE 10). Oil shall not be present between the contact faces of the table-top and the supporting frame. Oil on the cam face will lessen wear and promote smoothness of operation. The table shall be raised and permitted to drop a dozen times or more just prior to use if it has not been operated for some time. Care must be exercised to ensure that excess oil does not drain into the spacing between the pedestal and the steel plate or between the steel plate and the concrete base.

8.4.3.1.7 Calibration. The performance of the flow table shall be considered satisfactory if, in calibration tests, the table gives a flow value that does not differ by more than 5 percentage points from the assigned flow value of a suitable calibration material*.

**Such a material may be obtained from the Cement and Concrete Reference Laboratory at the National Bureau of Standards, Washington, D.C. 20234, U.S.A.*

8.4.3.2 Flow Table Mould. The mould for casting the flow specimen shall be of cast bronze or brass, constructed as shown in Figure 2. The Rockwell hardness number of the metal shall be not less than B25. The diameter of the top opening shall be 70 ± 0.5 mm for new moulds and the permissible variation shall be doubled for moulds in use. The surfaces of the base and top shall be parallel and at right angles to the vertical axis of the cone. The moulds shall have a minimum wall thickness of 5 mm. The outside of the top edge of the mould shall be shaped so as to provide an integral collar for convenient lifting of the mould. All surfaces shall be machined to a smooth finish. A circular shield approximately 250 mm in diameter, with centre opening approximately 100 mm in diameter, made of non-absorbent material that will not be attacked by cement shall be used with the flow mould to prevent mortar from spilling on the table-top.

8.4.3.3 Flow Table Caliper. A caliper shall be provided for measuring the diameter of the mortar after it has been spread by the operation of the table. The scale shall be machine-divided and the construction and accuracy of the instrument shall be such that the distance between the jaws shall be 100 ± 0.25 mm when the indicator is set at zero. The caliper shown in Figure 2 is graduated to indicate ¼ of actual flow, so that the reading of 4 measurements may be added to give the flow value, without the necessity of calculating the average of individual measurements.

8.4.4 Glassware

8.4.4.1 General. Glassware for analytical procedures, including volumetric flasks, burettes, pipettes, dispensing devices, etc., shall be carefully selected precision grade and shall be calibrated, if necessary, to meet the requirements of each operation.

8.4.4.2 Graduates

8.4.4.2.1 Glass graduates and dispensing devices used for measuring mixing water shall be made to deliver the indicated volume at 20°C. The main graduation lines shall be circles and shall be numbered. The least graduations shall extend a minimum of ⅛ of the perimeter and the intermediate graduations shall extend a minimum of ⅕ of the perimeter. The graduate used for any test shall be the smallest capacity that will measure the required volume of mixing water in 1 operation.

8.4.4.2.2 Permissible variations in glass graduates for physical tests shall be as shown in Table 9.

8.4.4.3 Le Chatelier Flask. The standard Le Chatelier flask conforming to the dimensions shown in Figure 3(a) or 3(b) shall be used.

8.4.5 Mixer and Accessories

8.4.5.1 General. The mixer shall be an electrically driven mechanical mixer of the epicyclic type, which imparts both a planetary and a revolving motion to the mixer paddle. The mixer shall have a minimum of 2 speeds controlled by definite mechanical means*. The first or slow speed shall revolve the paddle at a rate of 140 ± 5 r/min with a planetary motion of approximately 62 r/min. The second speed shall revolve the paddle at a rate of 285 ± 10 r/min, with a planetary motion of approximately 125 r/min. The electric motor shall be at least 125 W. The mixer shall be capable of adjustment so that when the bowl is in the mixing position the clearance between the lower end of the paddle and the bottom of the bowl shall be not greater than 2.5 mm, but not less than 0.75 mm, the approximate diameter of a grain of 20—30 standard Ottawa sand. This shall be accomplished by means of the clearance adjustment bracket shown in Figure 4, which shall be used to maintain the required clearance.†

**Rheostat adjustment of speed is not acceptable.*

†*When the bracket is in the proper position beneath the motor housing, the lugs are to the front and facing upward and the heads of the adjusting screws are to the rear and facing downwards in the path of the sliding frame that holds the bowl. It is intended that the bracket be fastened to the front housing connection by inserting replacement screws of appropriate size upward through the opening in each lug and into the existing threaded holes in the bottom of the motor housing. The original stops for the sliding frame are to be filed down if they prevent the frame from coming in contact with the adjustment screws.*

8.4.5.2 Paddle. The paddle shall be readily removable, made of stainless steel, and shall conform to the basic design shown in Figure 5. The dimensions of the paddle shall be such that when in the mixing position the paddle outline conforms to the contour of the bowl used with the mixer, and the clearance between corresponding points on the edge of the paddle and the side of the bowl in the position of closest approach shall be approximately 4 mm but not less than 0.75 mm.

8.4.5.3 Bowl. The removable mixing bowl shall have a nominal capacity of 4.5 L and shall be of general shape and comply with the limiting dimensions shown in Figure 6 and shall be made of stainless steel. The bowl shall be so equipped that it will be positively held in the mixing apparatus in a fixed position during the mixing procedure. A lid, made of non-absorbent material that will not be attacked by the cement, shall be provided.

8.4.5.4 Scraper. The scraper shall consist of a semi-rigid rubber blade attached to a handle about 150 mm long. The blade shall be about 80 mm long and 50 mm wide and tapered to a thin edge about 2 mm thick.

8.4.6 Sampling Tube. A sampling tube suitable for packaged cement is shown in Figure 7.

Note: *The sampling tube should be inserted diagonally into the bag through the valve. The air hole should be covered with the thumb as the sample is withdrawn.*

8.4.7 Sieves. The sieves required for the testing of cement are 1.00 mm, 710 µm, 500 µm, 355 µm, 250 µm, 180 µm, 125 µm, and 45 µm, and they shall conform to the requirements of CGSB Standard 8-GP-2M, Sieves, Testing, Woven Wire, Metric.

8.4.8 Tamper. The tamper shall be a non-absorptive, non-abrasive material such as urethane, medium hard rubber having a Shore A durometer hardness of 80 ± 10, or seasoned oak wood rendered non-absorptive by immersion for 15 min in paraffin at approximately 200°C and shall have a cross-section 13 mm × 25 mm and a length of approximately 130—150 mm. The tamping face of the tamper shall be flat and at right angles to the tamper.

8.4.9 Trowel. The trowel shall have a steel blade 100—150 mm in length, with straight edges.

8.4.10 Vicat and Gillmore Test Equipment

8.4.10.1 Vicat Apparatus. The Vicat apparatus shall consist of a frame A (see Figure 8), bearing a movable rod B*, weighing 300 ± 0.5 g, one end C being 10 ± 0.05 mm in diameter for a distance of at least 50 mm, the other having a removable needle D, 1 ± 0.05 mm in diameter, at least 50 mm long. The rod is reversible, and can be held in any desired position by a screw E, and has midway between the ends a mark F that moves over a scale (graduated in millimetres) attached to the frame A. The paste is held in a conical ring with internal dimensions G, 70 ± 3 mm in diameter at the base, 60 ± 3 mm in diameter at the top,

40 ± 1 mm high, of suitable non-absorbent, non-corrosive material resting on a glass plate H about 100 mm × 100 mm.

H Rod B of a new apparatus shall be of stainless steel having a hardness of not less than Rockwell C35.

8.4.10.2 Gillmore Needles

8.4.10.2.1 Mass and Dimensions. The mass and diameter of the needles shall be as follows:

(a) Initial needle:
  (i) Mass—115 ± 0.5 g;
  (ii) Diameter—2.12 ± 0.05 mm;

(b) Final needle:
  (i) Mass—450 ± 0.5 g;
  (ii) Diameter—1.06 ± 0.05 mm.

8.4.10.2.2 The needle tips shall be cylindrical for a distance of about 5 mm. The needle ends shall be plane and at right angles to the axis of the rod and shall be maintained in a clean condition.

Note: *The Gillmore needles should be mounted as shown in Figure 9.*

8.4.11 Volume Measure. A cylindrical measure having an inside diameter of 75 ± 2 mm and a depth of approximately 90 mm shall be adjusted by standardization with water to contain 400 ± 1 mL at 23°C (see Figure 10). The measure shall have a uniform wall thickness. The thickness of the wall and bottom shall be not less than 3 mm. The total mass of the empty measure shall be not more than 900 g. The measure shall be made of a metal not attacked by the cement mortar.

Note: *A satisfactory mould may be machined from seamless steel tubing or nominal* 75 mm *wrought iron pipe, to the bottom of which a steel disk about* 3 mm *in thickness is welded.*

8.4.12 Water Retention Test Apparatus

8.4.12.1 For the water retention test, an apparatus essentially the same as that shown in Figure 11 shall be used. This apparatus consists of an aspirator controlled by a mercury column relief and connected by way of a 3-way stopcock to a funnel upon which rests a perforated dish.

8.4.12.2 The bore of the stopcock shall have a 4 mm diameter, and connecting glass tubing shall have a minimum diameter of 4 mm. A mercury manometer, connected as shown in Figure 11, indicates the vacuum.

8.4.12.3 A thin coating of cup grease shall be applied to the area of contact between the dish and the funnel. If difficulty is experienced in securing a satisfactory vacuum, a rubber gasket may be sealed to the top of the funnel.

8.4.12.4 The perforated dish shall be made of metal not attacked by masonry mortar. The metal in the base of the dish shall have a minimum thickness of 1.7 mm, and a maximum thickness of 1.9 mm, and conform to Figure 11.

8.4.12.5 Hardened filter paper equivalent to Carl Schleicher and Schuell filter paper No. 575 or Whatman No. 50 shall be used. It shall be of such a diameter that it will lie flat and completely cover the bottom of the dish.

8.4.13 Weighing

8.4.13.1 Analytical Balance. The balances shall be of an analytical type and shall have a capacity of not more than 200 g. The balances shall be capable of reproducing results within 0.0002 g with an accuracy of ±0.0002 g. Rapid-weighing devices that may be provided with such balances shall not increase the basic inaccuracy by more than 0.0001 g at any reading and with any load within the rated capacity of the balance.

8.4.13.2 Scale. On scales in use, the permissible variation at a load of 1000 g shall be ±1.0 g; at a load of 2000 g the permissible variations shall be ±2.0 g. The permissible variation on new scales shall be 1/2 of these respective values. The sensibility reciprocal shall be not greater than twice the permissible variation.

Note: *The sensibility reciprocal is a measure of the sensitiveness of a balance and is the mass required to move the position of the pointer one division.*

8.4.13.3 Weights

8.4.13.3.1 Weights used for analytical procedures and cement fineness shall conform to Class S-1 requirements of the United States National Bureau of Standards as described in NBS Circular 547. The weights shall be checked at least once a year and adjusted, if necessary, to within allowable tolerances for Class S-1 weights. For purposes of checking, a laboratory shall have available a set of reference weights conforming to Class S requirements. The reference weights shall be certified by the National Research Council of Canada or the U.S. Bureau of Standards. Class S-1 permissible variations are shown in Table 10.

8.4.13.3.2 The permissible variations in weights used in weighing materials for the physical testing of mortar and paste specimens are shown in Table 10. For new weights, the permissible variation shall be 1/2 the value shown in Table 10.

8.4.14 Wet-Sieving Equipment

8.4.14.1 Pressure Gauge. The pressure gauge shall be a minimum of 75 mm in diameter, shall be graduated in 5 kPa increments, and shall have a maximum capacity of 200 kPa. The accuracy at 70 kPa shall be ±1.5 kPa.

8.4.14.2 45 μm Sieve. The sieve frame shall be of metal not subject to corrosion by water and shall be circular, 50 ± 5 mm in diameter. The depth of the sieve from the top of the frame to the cloth shall be 75 ± 5 mm. The frame shall be flanged at the base to form a smooth-surfaced extension approximately 90 mm in diameter. The sieve cloth is secured to the flange by means of a retaining ring of similar size fitted with screws. The retaining ring is equipped with legs of sufficient length, 10 mm minimum, to allow air circulation beneath the sieve cloth. The sieve frame shall be fitted with a 45 μm cloth

conforming to the requirements of CGSB Standard 8-GP-2M, Sieves, Testing, Woven Wire, Metric. The cloth is mounted in the frame without distortion, looseness, or wrinkling. For a sieve fabricated by soldering the cloth to the frame, the joint shall be made smooth to prevent the cement from catching in the space between the sieve cloth and the frame. The pieces shall be set firmly together to prevent cement from lodging in the joints between the sieve cloth and the frame.

8.4.14.3 Spray Nozzle. The spray nozzle shown in Figure 12 shall be constructed of metal not subject to corrosion by water, and shall be 17.5 mm in inside diameter with a central hole drilled in line with the longitudinal axis, an intermediate row of 8 holes drilled 6.0 mm centre-to-centre at an angle of 5° from the longitudinal axis, and an outer row of 8 holes drilled 11.0 mm centre-to-centre at an angle of 10° from the longitudinal axis. All holes shall be 0.50 mm in diameter.

8.5 Materials

8.5.1 Chemicals

8.5.1.1 General. All reagents shall conform to the American Chemical Society Specifications for Reagent Chemicals, where such specifications are available. Where no such specification governs, the best grade obtainable shall be used.

8.5.1.2 Concentrated Reagents. When acids and ammonium hydroxide are specified by name or chemical formula only, it shall be understood that concentrated reagents of the following relative densities or concentrations are intended:

(a) Hydrochloric acid (HCl)—relative density 1.18;

(b) Nitric acid (HNO_3)—relative density 1.42;

(c) Phosphoric acid (H_3PO_4)—85%; and

(d) Ammonium hydroxide (NH_4OH)—relative density 0.90.

8.5.1.3 Dilute Reagents. Concentrations of dilute acids and NH_4OH, except when standardized, shall be specified as a ratio stating the number of volumes of the concentrated reagent to be diluted with a given number of volumes of water, as in the following example: HCl (1:99) means 1 volume of HC1 diluted with 99 volumes of water.

8.5.1.4 Standard Solutions

8.5.1.4.1 Potassium Dichromate ($K_2Cr_2O_7$) Solution. Dissolve 2.457 g of $K_2Cr_2O_7$ in water and dilute 1 L. Standardize against 1 g of standard Portland cement issued by the National Bureau of Standards, Washington, D.C. (Standard Sample No. 1014 or its replacements) in the same manner as directed for the determination of ferric oxide (Fe_2O_3) in cement (see Clause 6.3.5.1). Calculate the Fe_2O_3 equivalent (E) of the solution in grams per millilitre as follows:

$$E = \frac{\text{Certified per cent } Fe_2O_3}{100 \times \text{mL } K_2Cr_2O_7 \text{ solution used}}$$

8.5.1.5 Non-standard Solutions

8.5.1.5.1 General. Concentrations of non-standard solutions prepared by dissolving a given mass of the solid reagent in a solvent shall be specified in grams of the reagent per litre of solution, and it shall be understood that water is the solvent except as stated in Clauses 8.5.1.5.2 and 8.5.1.5.3, for example: NaOH (10 g/L) means 10 g of sodium hydroxide (NaOH) dissolved in water and diluted with water to a volume of 1 L.

8.5.1.5.2 Ammonium Nitrate (NH_4NO_3) Wash Solution (100 g/L). Dissolve 100 g of NH_4NO_3 in water, add 200 mL of NH_4OH, and dilute to 1 L with water.

8.5.1.5.3 Stannous Chloride Solution (50 g/L). Dissolve 5 g of $SNCl_2.2H_2O$ in 10 mL of HCl and dilute to 100 mL with water. Add scraps of iron-free granulated tin and boil until the solution is clear. Keep the solution in a closed bottle containing metallic tin.

8.5.1.6 Standard Liquids. Kerosene free of water, or naptha having a gravity not lighter than 62° API, shall be used in the mass density determination.

8.5.1.7 Indicators

8.5.1.7.1 Methyl Red (1 g/L). Dissolve 0.1 g of methyl red (sodium salt) in water and make up to 100 mL.

8.5.1.7.2 Barium Diphenylamine Sulphonate (3 g/L). Dissolve 0.3 g of barium diphenylamine sulphonate in water and make up to 100 mL.

8.5.2 Gypsum for Sulphate Resistance Tests

8.5.2.1 The gypsum used for the addition to cement shall be high grade natural gypsum with 100% passing the 125 μm sieve and at least 90% passing the 45 μm sieve.

Note: *Any gypsum with an SO_3 content of 44.0—46.6% is acceptable.*

8.5.2.2 If the SO_3 content of the gypsum is unknown, the gypsum shall be analysed for SO_3 content in accordance with the CSA A82.20-M Series, Methods of Testing Gypsum and Gypsum Products.

8.5.3 Sand

8.5.3.1 General. The sand used for the preparation of mortar shall be silica sand from Ottawa, Illinois. The temperature of the sand shall be maintained between 20°C and 26°C. Care shall be exercised to prevent segregation of the sand when filling bins or removing sand from the bins or sacks. The formation of craters or slopes must be avoided in the sand storage bin.

Note: *Gravity discharge systems should not be used.*

Sieve size requirements in Table 11 have been changed to the R20/3 Series of Sieves.

This scale differs from the R40 series used to prepare Graded and Standard Sand to the requirements of ASTM Specification C778, Standard Sand.

In view of the discrepancy it has been established that, regardless of the different sieve sizes, the two specification limit curves (CSA and ASTM) are so aligned that sand that falls outside Table 11 limits will, as well, fail to meet C778 requirements for Graded Sand.

In the case where sand grading meets ASTM requirements but does not conform to Table 11 or the requirement specified for Standard Sand in Clause 8.5.3.3 its use will be permitted, provided that the deviation is noted and the resulting data is so qualified.

8.5.3.2 Graded Sand. Graded Sand shall be natural silica sand and shall conform to the size distribution requirements recorded in Table 11.* The sieving operation shall be performed in the manner specified in Clause 7.3.1.2, Sand Gradation.

**There is a possibility of variation in size between the specified sieve gradings, as well as changes in surface texture and coating of the particles that will alter the characteristics of the mortar.*

8.5.3.3 Standard Sand. Standard Sand shall be natural silica sand. The sand shall be considered standard when it passes the 1.00 mm sieve, not more than 50 g are retained on the 710 μm sieve and 98 ± 2 g are retained on the 500-μm sieve after 5 min continuous sieving of a 100 g sample. The sieving operation shall be performed in the manner specified in Clause 7.3.1.2, Sand Gradation.

8.5.4 Water

8.5.4.1 Chemical Determinations. References to water shall be understood to mean distilled water.

8.5.4.2 Physical Determinations. In general, water fit for drinking is satisfactory for cement testing. In case of doubt, distilled water shall be used for comparison or reference. The temperature of the water shall be maintained between 20°C and 26°C.

9. Method of Uniformity Calculation

9.1 General. The coefficient of variation shall be determined on the results of the 30 most recent consecutive samples taken from a single manufacturing source over a period not exceeding 6 months and tested at the same laboratory. A value that failed the uniformity requirements shall not be included in subsequent calculations of the coefficient of variation. Compressive strength testing shall be in accordance with Clause 7.5.3.

Note: *Factors other than the intrinsic variations in the quality of cement, such as operator technique or changes in the quality of testing sand, can contribute substantially to the overall variation and should be considered in evaluating these results.*

9.2 Sample and Sampling. A sample shall be a single sample taken as described in Clause 4.

9.3 Calculation Formulae

9.3.1 Average, $\bar{X}$, shall be the average strength of n samples:

$$\bar{X} = \frac{X_1 + X_2 + X_3 + \ldots X_n}{n}$$

where X_1, X_2, X_3,...X_n are the strength results of individual samples and n is the total number of samples (30) tested.

9.3.2 Standard deviation, σ, shall be calculated as either:

$$\sigma = \sqrt{\frac{X_1^2 + X_2^2 + X_3^2 + \ldots X_n^2}{n} - \bar{X}^2}$$

or

$$\sigma = \frac{1}{n}\sqrt{n(X_1^2 + X_2^2 + X_3^2 + \ldots X_n^2) - (X_1 + X_2 + X_3 + \ldots X_n)^2}$$

where
n = 30

9.3.3 Coefficient of variation, V, shall be calculated as:

$$V = \frac{\sigma}{\bar{X}} \times 100$$

and expressed as a percentage.

Table 1
Chemical Requirements—Portland Cements

Property	Normal	Moderate	High Early-Strength	Low Heat of Hydration	Sulphate Resistant
	Maximum, Per Cent				
Loss on Ignition	3.0†	3.0	3.0	3.0	3.0
Insoluble Residue	1.0	0.7	0.7	0.7	0.7
Sulphur Trioxide					
$C_3A > 7.5\%$	3.5*	—	4.5*	—	—
$C_3A \leq 7.5\%$	3.0*	3.0	3.5*	2.5	2.5
Magnesium Oxide	5.0	5.0	5.0	5.0	5.0
Tricalcium Aluminate	—	7.5	—	5.5	3.5

**The Committee recognizes the requirements of "Optimum SO_3 content in Portland cements", and further recognizes that some Portland cements may be unable to meet the SO_3 level required by this Standard. Therefore, for acceptance purposes, designated Portland cements may comply either with the above requirements or with an expansion limit of 0.020% at 14 d when tested in accordance with Clause 7.5.5.*

†A Loss on Ignition of 3.5% maximum is allowed for normal Portland cement (Type 10) provided that such cement when tested in accordance with Clause 6.3.1 but at a furnace temperature of 550 ± 25° C shows a loss in mass of not more than 3.0%.

Table 2
Physical Requirements—Portland Cements

Property	Normal	Moderate	High Early-Strength	Low Heat of Hydration	Sulphate Resistant
Fineness*					
Minimum Passing 45 μm Sieve, Per Cent	72	72	—	—	72
Soundness†					
Maximum Expansion, Per Cent	1.0	1.0	1.0	1.0	1.0
Sulphate Resistance at 14 d					
Maximum Expansion, Per Cent	—	0.050‡	—	—	0.035
Setting Time, Minutes					
Minimum	45	60	45	90	60
Maximum	360	360	250	360	360
Heat of Hydration					
7 d Maximum, kJ/kg	—	300‡	—	275	—

(Continued)

July 1986
(Replaces p. 32, May 1983)

Table 2 (Concluded)

Property	Normal	Moderate	High Early-Strength	Low Heat of Hydration	Sulphate Resistant
Compressive Strength** Minimum, MPa Age at Test, Days 1	—	—	12.5	—	—
3	12.5	10.0	22.0	8.5	10.5
7	18.0	16.0	—	—	16.0
28	26.5	26.5	—	25.0	26.5
91	—	—	—	33.0††	—
Early Stiffening of Cement Paste	‡‡	‡‡	‡‡	‡‡	‡‡

**See Clause 8.4.7.*

†*See Clause 3.2.2.1.*

‡*The requirement of either heat of hydration or sulphate resistance may be specified at the option of the purchaser.*

***The strength at any age shall be higher than that of the preceding age, and should be reported to the nearest* 0.1 MPa.

††*This value indicates requirements to be specified at the option of the purchaser.*

‡‡*This property and test method, as described in Appendix A, may be specified at the option of the purchaser. Clause A1.4, Interpretation of Data, sets forth guidance on selection of requirements.*

Table 3
Equipment and Materials for
Chemical Analysis of Portland Cement

Apparatus and Materials	Clause Reference
Glassware	8.4.4
Analytical Balance	8.4.13.1
Chemicals	8.5.1
Water	8.5.4.1

Table 4
Test Procedures for Chemical Analysis

Test Procedure	Clause Reference
Loss on Ignition	6.3.1
Insoluble Residue	6.3.2
Sulphur Trioxide	6.3.3
Tricalcium Aluminate	6.3.4
Ferric Oxide	6.3.5
Combined Oxides of NH_4OH Group	6.3.6
Alumina	6.3.7
Magnesia	6.3.8

Table 5
Equipment and Materials for
Physical Testing of Portland Cements

Apparatus and Material	Clause Reference
Room Temperature and Humidity	8.3.1
Humidity Cabinet	8.3.2
Water Storage	8.3.3
Glass Graduates	8.4.4.2
Balance	8.4.13.1
Scale	8.4.13.2
Weights	8.4.13.3
Mixing Water	8.5.4.2

Table 6
Physical Tests of Portland Cements

Test	Clause Reference
Powder Test	
Fineness	7.3.1
Paste Tests	
Paste Mixing	7.4.1
Normal Consistency	7.4.2
Setting Time, Vicat	7.4.3
Autoclave Soundness Test	7.4.4
Heat of Hydration	7.4.5
Mortar Tests	
Mortar Mixing	7.5.1
Determination of Mortar Flow	7.5.2
Compressive Strength	7.5.3
Sulphate Resistance	7.5.4
Sulphate Expansion	7.5.5

Table 7
Equipment and Materials

Item	Clause Reference
Autoclave	8.4.1
Compression Test Equipment	8.4.2
Flow Table	8.4.3
Glassware	8.4.4
Mixer	8.4.5
Sampling Tube	8.4.6
Sieves	8.4.7
Tamper	8.4.8
Trowel	8.4.9
Vicat and Gillmore Test Equipment	8.4.10
Volume Measure	8.4.11
Water Retention Test Apparatus	8.4.12
Weighing Equipment	8.4.13
Wet-Sieving Equipment	8.4.14
Chemicals	8.5.1
Gypsum for Sulphate Resistance Tests	8.5.2
Sand	8.5.3
Water	8.5.4

Table 8
Dimensional Requirements for Moulds

Measurement	Mould Type	
	F mm	M mm
Size of Prism	25 × 25 × 160	25 × 25 × 285
Effective Gauge Length of Prism	120 ± 1.25	250 ± 2.5
Interior Width and Height of Each Specimen Compartment for New Moulds and Moulds in Use	25 ± 0.7	25 ± 0.7
Thickness of Base Plate, End Plate, Gauge Stud Holder	10.0	10.0
Side Plate	6.0	6.0
Portion of Gauge Studs Extending into the Specimens		
Diameter	6.0	6.0
Total Length	17.5 ± 0.5	17.5 ± 0.5
Knurled Length	6.0	6.0

Table 9
Requirements for Glass Graduates

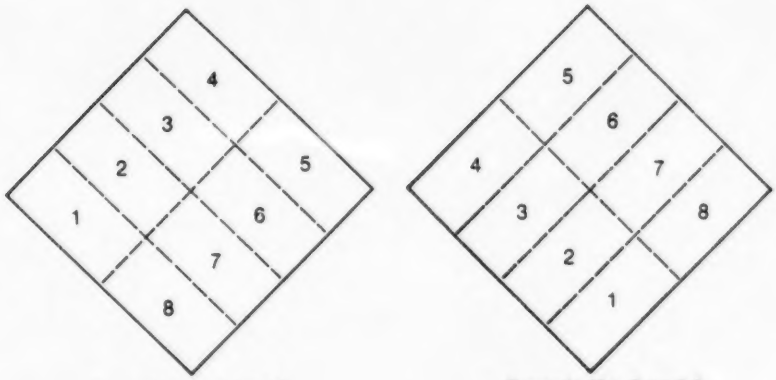
Capacity mL	Permissible Variation mL	Least Graduation mL
500	± 2	5
200	± 1	2
150	± 1	1
100	± 1	1

Table 10
Permissible Variation for Laboratory Weights

Weights Used in Paste and Mortar Tests		Weights Used in Chemical Analysis and Cement Fineness Test		
Mass	Permissible Variation	Mass		Permissible Variation Class S-1 (NBS)
g	± g	g	mg	± mg
1000	0.5	100		1.0
900	0.45	50		0.60
750	0.4	30		0.45
500	0.35	20		0.35
300	0.3	10		0.25
250	0.25	5		0.18
200	0.2	3		0.15
100	0.15	2		0.13
50	0.1	1		0.10
20	0.05		500	0.080
10	0.04		300	0.070
5	0.03		200	0.060
2	0.02		100	0.050
1	0.01		50	0.042
			30	0.038
			20	0.035
			10	0.030
			5	0.028
			3	0.026
			2	0.025
			1	0.025

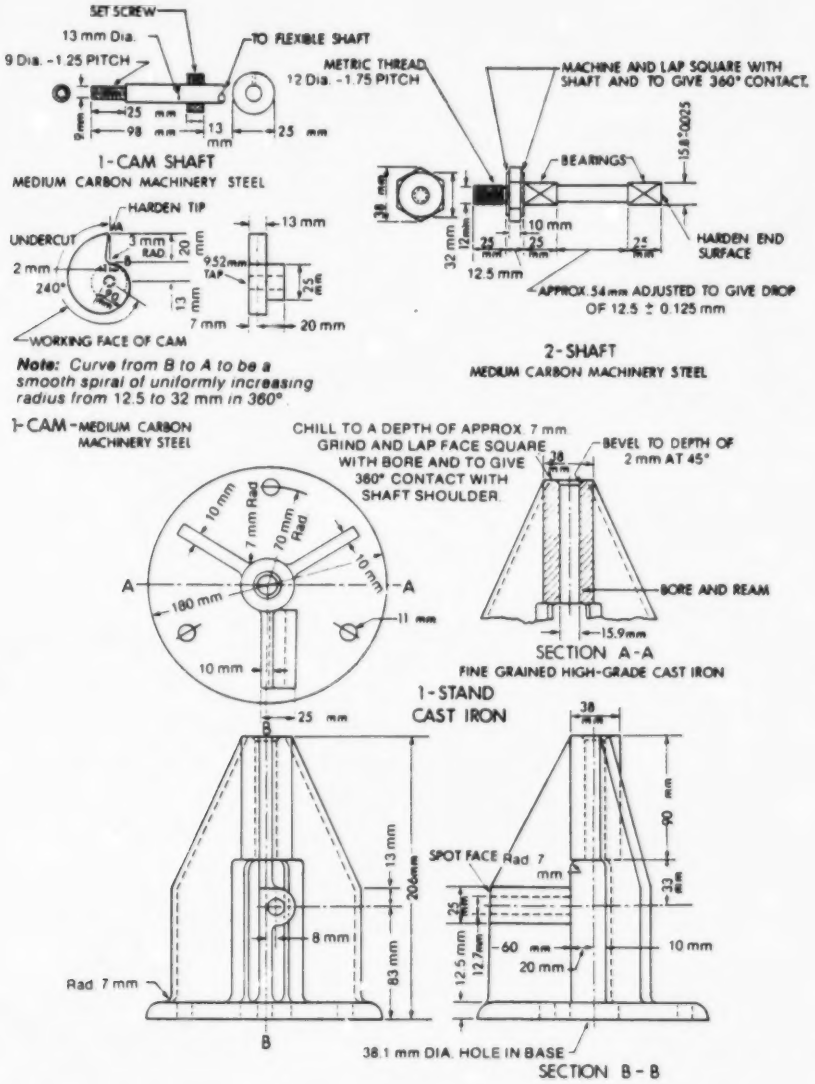
Table 11
Size Distribution Requirement for Graded Sand

Sieve Designation	Percentage Retained on Sieve
180 µm	97 ± 3
250 µm	88 ± 5
355 µm	50 ± 5
500 µm	10 ± 3
100 mm	0



Rounds No. 1 and 3 Rounds No. 2 and 4

Figure 1
Tamping Order


SET SCREW
13 mm Dia.
TO FLEXIBLE SHAFT
9 Dia. -1.25 PITCH
METRIC THREAD
12 Dia. -1.75 PITCH
MACHINE AND LAP SQUARE WITH SHAFT AND TO GIVE 360° CONTACT.
BEARINGS
HARDEN END SURFACE
1-CAM SHAFT
MEDIUM CARBON MACHINERY STEEL
HARDEN TIP
UNDERCUT
WORKING FACE OF CAM
Note: Curve from B to A to be a smooth spiral of uniformly increasing radius from 12.5 to 32 mm in 360°.
12.5 mm
APPROX. 54 mm ADJUSTED TO GIVE DROP OF 12.5 ± 0.125 mm
2-SHAFT
MEDIUM CARBON MACHINERY STEEL
1-CAM - MEDIUM CARBON MACHINERY STEEL
CHILL TO A DEPTH OF APPROX. 7 mm
GRIND AND LAP FACE SQUARE WITH BORE AND TO GIVE 360° CONTACT WITH SHAFT SHOULDER.
BEVEL TO DEPTH OF 2 mm AT 45°
BORE AND REAM
SECTION A-A
FINE GRAINED HIGH-GRADE CAST IRON
1-STAND CAST IRON
SPOT FACE Rad. 7 mm
Rad. 7 mm
38.1 mm DIA. HOLE IN BASE
SECTION B-B

Note: *The mass of the table-top and shaft assembly shall be* 4.1 ± 0.05 kg.

Figure 2
Flow Table and Accessory Apparatus

(Continued)

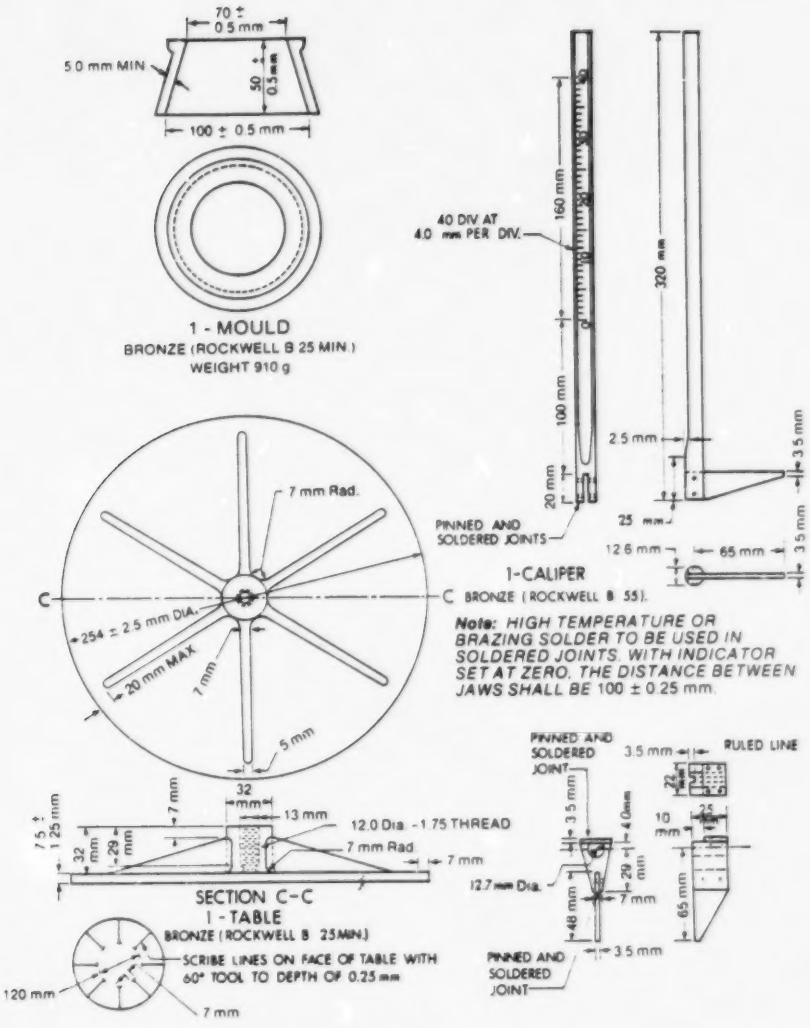


Figure 2 (Concluded)
Flow Table and Accessory Apparatus

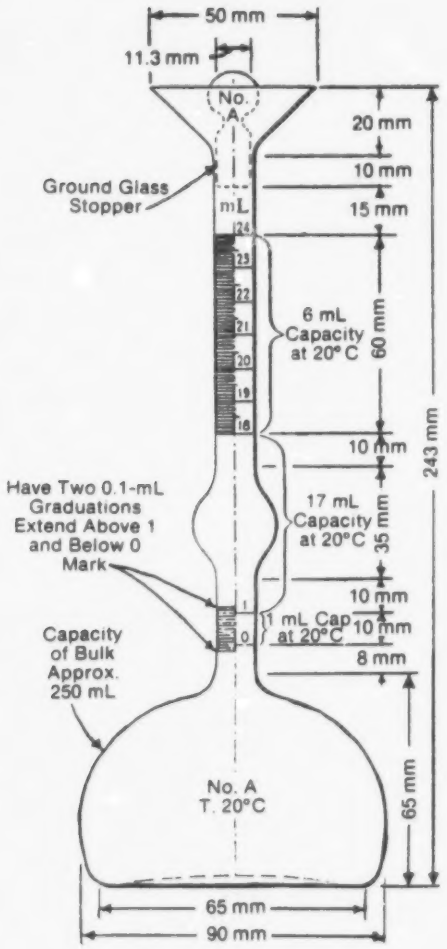


Figure 3(a)
Le Chatelier Flask — Original

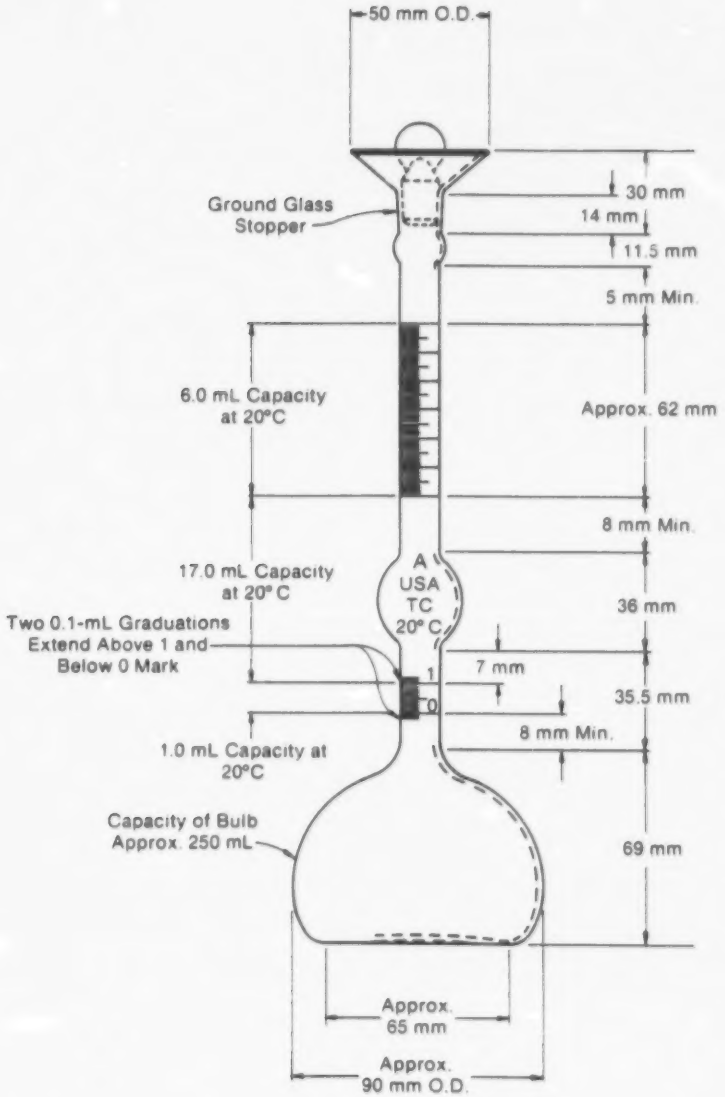
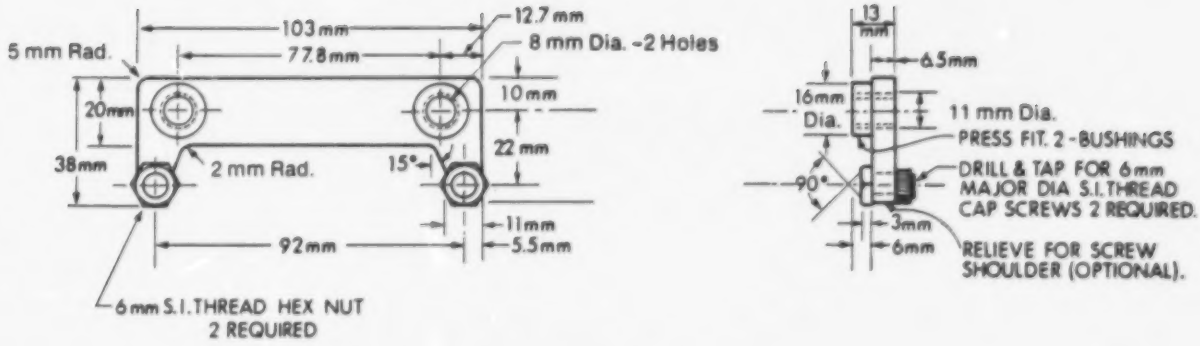


Figure 3(b)
Le Chatelier Flask — Redesigned



Note: *Plate and bushings — brass.*
Screws and nuts — steel.

Figure 4
Clearance Adjustment Bracket

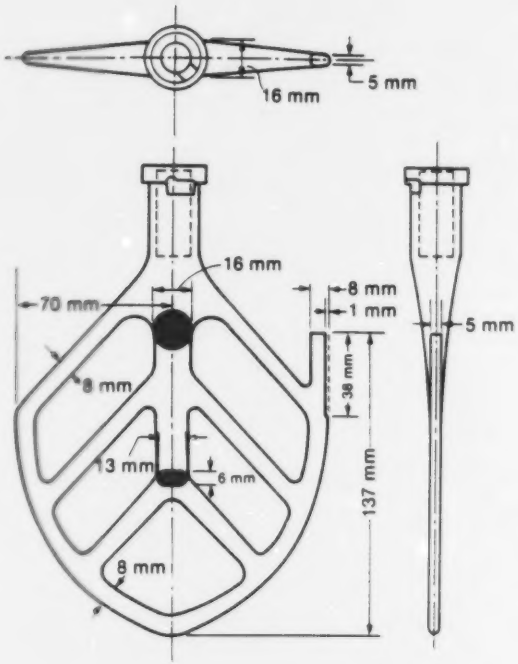


Figure 5
Paddle

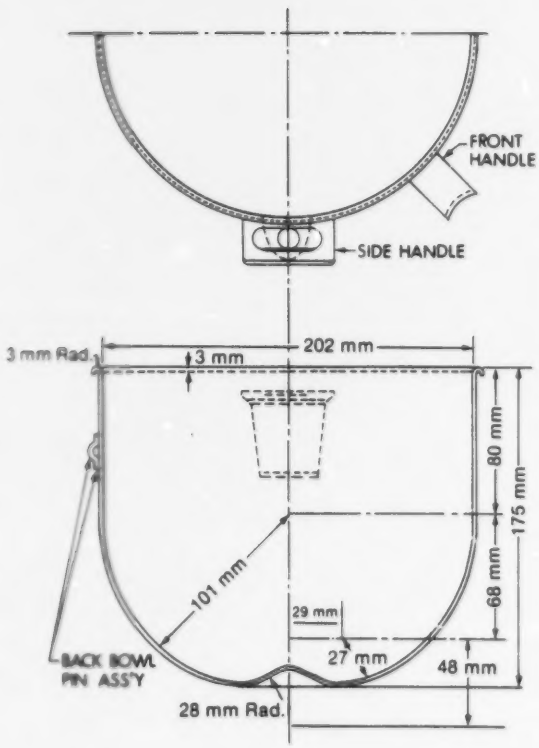
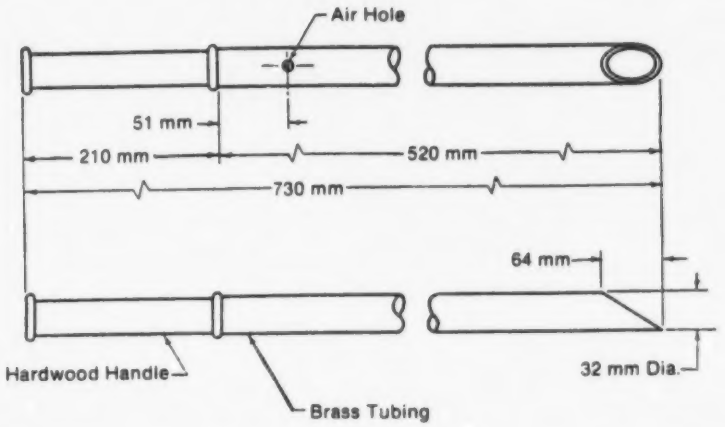


Figure 6
Mixing Bowl



Approx. Vol. = 320 cm³

Figure 7
Sampling Tube

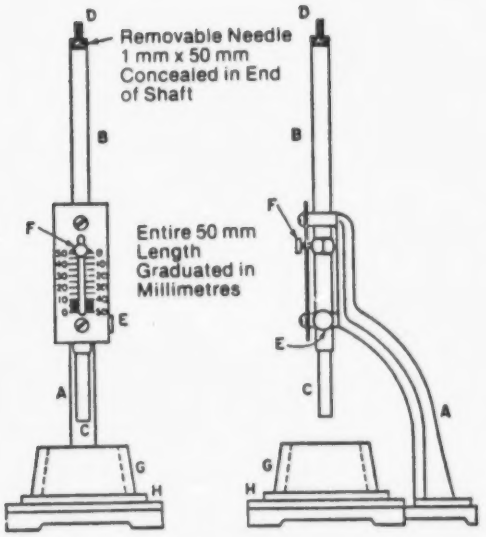


Figure 8
Vicat Apparatus

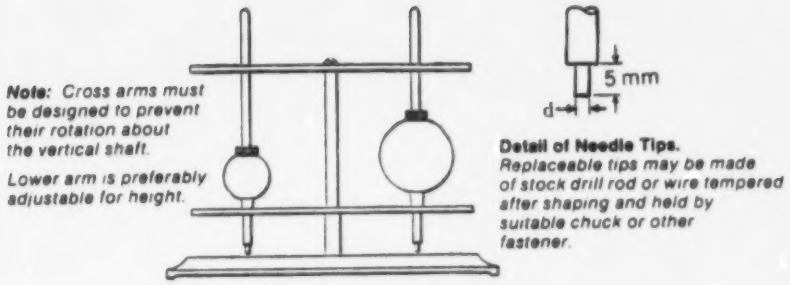

Note: Cross arms must be designed to prevent their rotation about the vertical shaft.
Lower arm is preferably adjustable for height.
5 mm
d
Detail of Needle Tips.
Replaceable tips may be made of stock drill rod or wire tempered after shaping and held by suitable chuck or other fastener.

Figure 9
Gillmore Needles

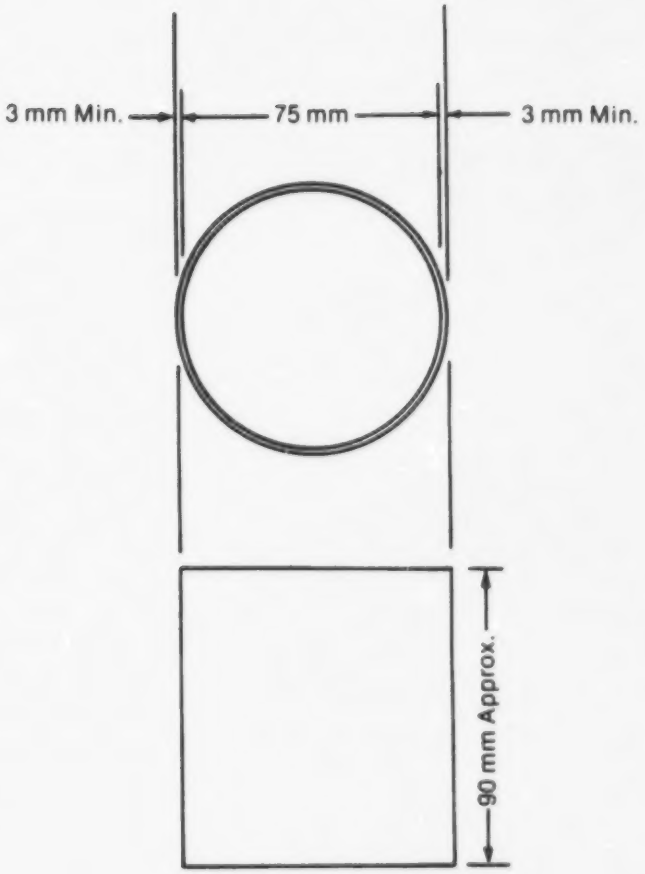


Figure 10
400-mL Measure

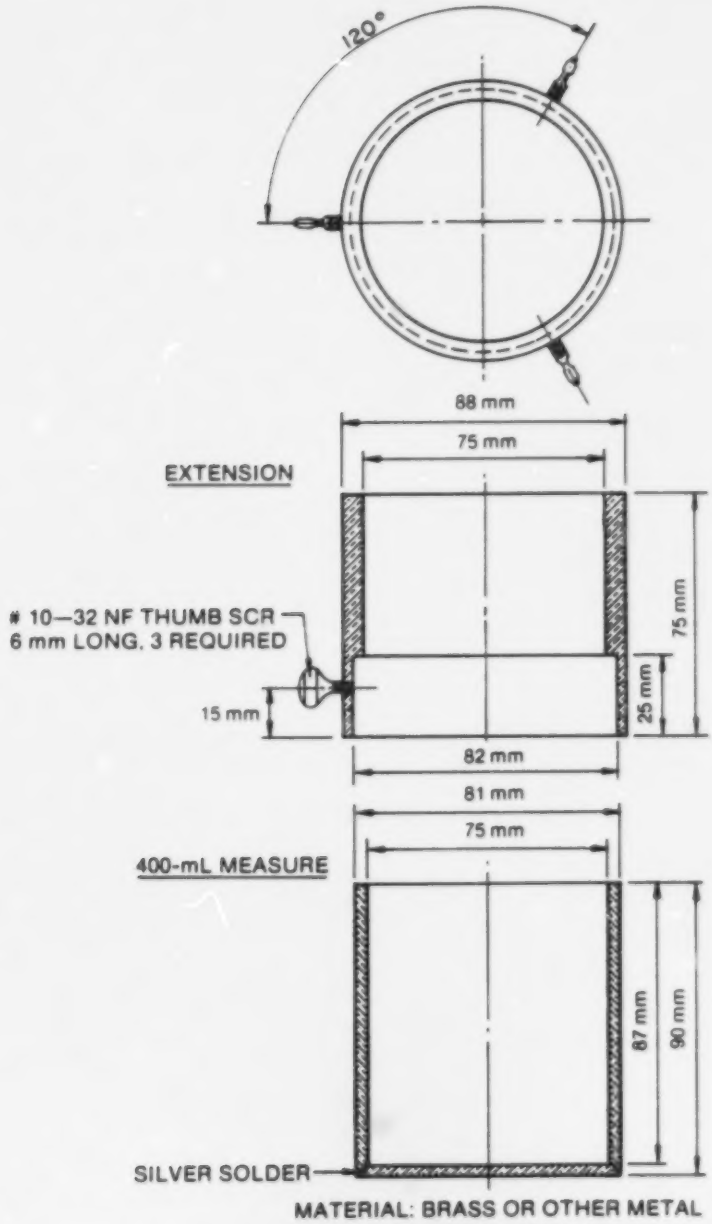
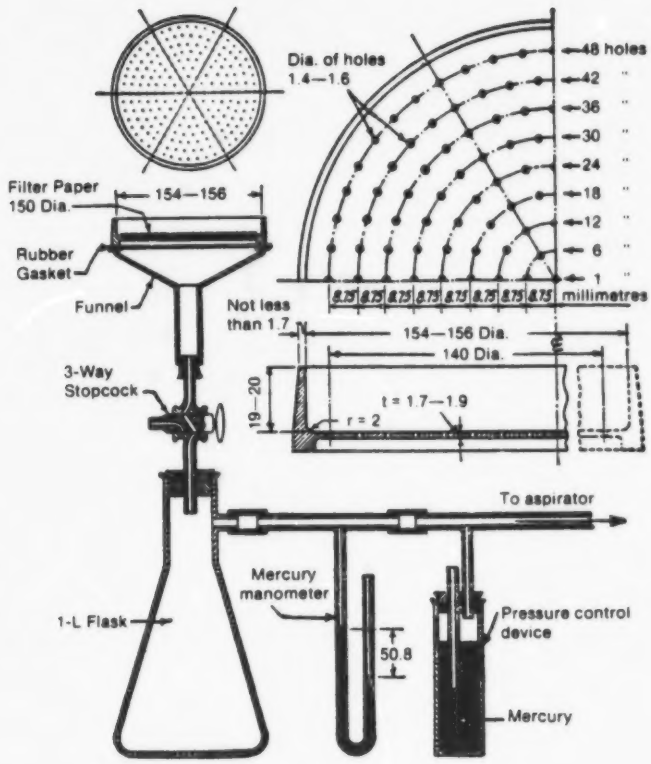


Figure 10A
Extension for 400-mL Measure



Notes:
(1) *All dimensions given are in millimetres.*
(2) *The gasket shall be of synthetic rubber. The stopcock shall be* 4 mm. *The bore of the tubing shall be at least* 4 mm. *A check valve or water trap, or both, are suggested for connection to the aspirator.*

Figure 11
Apparatus Assembly for the Water Retention Test

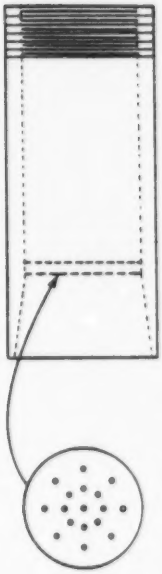


Figure 12
Spray Nozzle with Seventeen 0.50-mm Holes

Appendix A

Early Stiffening of Cement Paste

Note: *This Appendix is not a mandatory part of this Standard but may be made mandatory by specific reference to it in a purchase agreement.*

A1. Early Stiffening of Cement Paste

A1.1 Equipment. The equipment used in determining early stiffening shall conform to the following requirements:

(a) Weighing equipment (see Clause 8.4.13);

(b) Graduates (see Clause 8.4.4.2);

(c) Vicat apparatus (see Clause 8.4.10.1);

(d) Trowel (see Clause 8.4.9);

(e) Mixer and accessories (see Clause 8.4.5).

A1.2 Procedure

A1.2.1 A 500 g sample of dry cement shall be mixed with a measured amount of water in a mechanical mixer in accordance with Clause A1.2.2.

A1.2.2 Place the dry paddle and the dry bowl in the mixing position in the mixer. Then introduce the materials for a batch into the bowl and mix in the following manner:

(a) Place all the mixing water in the bowl;

(b) Add the cement to the water and allow 30 s for the absorption of the water;

(c) Start the mixer and mix at slow speed (140 ± 5 r/min) for 30 s;

(d) Stop the mixer for 15 s and during this time scrape down into the batch any paste that may have collected on the sides of the bowl; and

(e) Start the mixer at medium speed (285 ± 10 r/min) and mix for 2 min and 30 s.

A1.2.3 Manipulation. Cement paste prepared as described in Clause A1.2.2 shall be quickly formed into a ball with the gloved hands. The ball, resting in the palm of the hand, shall be pressed into the larger end of the conical ring held in the other hand, completely filling the ring with paste. The excess at the larger end shall be removed by a single movement of the palm of the hand. The ring shall then be placed on its larger end on a glass plate and the excess at the smaller end sliced off at the top of the ring by 2 oblique strokes, in opposite directions, of a sharp-edged trowel held at a slight angle with the top of the ring. If necessary, the top surface shall be smoothed by not more than 2 light strokes of the trowel. During these operations care shall be taken not to compress the paste. The paste confined in the ring, resting on the plate, shall be placed under the rod and the larger end (C) shall be brought into contact with the surface of the paste and the set screw tightened; the scale shall then be read and the rod released 20 s after completion of mixing. The portion of the plunger coming into contact with the cement paste shall be kept clean, and the apparatus shall be free from all vibration during the test.

A1.2.4 Initial Penetration. The paste shall have the proper consistency when the rod settles to a point 32 ± 4 mm below the original surface 30 s after being released. Trial pastes shall be made with varying percentages of water until the proper consistency is obtained. Each trial shall be made with fresh cement. The penetration noted at proper consistency shall be recorded as the initial penetration.

Note: *If a remix procedure is planned, return the excess paste to the bowl immediately after releasing the rod for the initial penetration measurement. Cover the bowl and mixing paddle with a lid.*

A1.2.5 Final Penetration. After completion of the initial reading, the plunger shall be removed from the paste and cleaned. The ring and plate shall be reset in a new position. This operation shall be performed with as little disturbance as possible to the paste confined in the ring. The larger end of the rod shall again be brought into contact with the surface of the paste and the set screw tightened; the scale shall then be read. The rod shall be released a second time 5 min after completion of the mixing period and the final penetration shall be determined 30 s after the rod is released.

A1.3 Presentation of the Data. Calculate the per cent penetration as follows:

$$\text{Per cent penetration} = \frac{\text{final penetration}}{\text{initial penetration}} \times 100$$

The penetration shall be recorded to the nearest millimetre and the per cent penetration shall be recorded to the nearest per cent.

A1.4 Interpretation of Data. No fixed values are specified herein for acceptability under this test; however, a penetration of 50% greater indicates a cement free from early stiffening tendencies. Penetration between 35 and 50% indicates a tendency for early stiffening. Penetration less than 35% indicates a potential for early stiffening.

A1.5 Remix

A1.5.1 An investigation into the nature of a rapid stiffening cement may be carried out by remixing the paste in accordance with Clause A1.5.2.

A1.5.2 The procedure for remixing shall be as follows:

(a) The paste shall be immediately returned to the bowl after measurement of the 5 min penetration;

(b) Start the mixer, raise the bowl into mixing position, and remix the contents of the bowl at medium speed for 1 min;

(c) The ring shall be filled and the per cent penetration determined in accordance with Clauses A1.2.3, A1.2.4, and A1.2.5.

A1.5.3 Remix Interpretation. Early stiffening due to mild dehydration of gypsum (commonly called false set) will be overcome by remixing. If the per cent penetration does not recover after remixing, then a more severe form of early stiffening is present.

Appendix B

Precision of Test Methods

Note: *This Appendix is not a mandatory part of this Standard.*

B1. At this time, the relatively small number of laboratories conducting cement tests in Canada makes it impractical to develop precision statements for the tests required according to Table 1 (Chemical Requirements) and Table 2 (Physical Requirements) of this Standard.

The user of this Standard interested in the subject may consult the Precision and Bias statements of the most recent edition of the ASTM Standard Methods of Chemical Analysis and Physical Testing of Portland Cement, as listed below:

Chemical analysis	ASTM C114
Fineness	ASTM C430
Soundness	ASTM C151
Sulphate resistance	ASTM C452
Setting time	ASTM C191
Heat of hydration	ASTM C186
Compressive strength	ASTM C109

Designation: C 150 – 86

Standard Specification for Portland Cement[1]

This standard is issued under the fixed designation C 150; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This specification has been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

1. Scope

1.1 This specification covers eight types of portland cement, as follows (see Note):

1.1.1 *Type I*—For use when the special properties specified for any other type are not required.

1.1.2 *Type IA*—Air-entraining cement for the same uses as Type I, where air-entrainment is desired.

1.1.3 *Type II*—For general use, more especially when moderate sulfate resistance or moderate heat of hydration is desired.

1.1.4 *Type IIA*—Air-entraining cement for the same uses as Type II, where air-entrainment is desired.

1.1.5 *Type III*—For use when high early strength is desired.

1.1.6 *Type IIIA*—Air-entraining cement for the same use as Type III, where air-entrainment is desired.

1.1.7 *Type IV*—For use when a low heat of hydration is desired.

1.1.8 *Type V*—For use when high sulfate resistance is desired.

1.2 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

C 33 Specification for Concrete Aggregates[2]

C 109 Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or 50-mm Cube Specimens)[3]

C 114 Methods for Chemical Analysis of Hydraulic Cement[3]

C 115 Test Method for Fineness of Portland Cement by the Turbidimeter[3]

C 151 Test Method for Autoclave Expansion of Portland Cement[3]

C 183 Methods of Sampling and Acceptance of Hydraulic Cement[3]

C 185 Test Method for Air Content of Hydraulic Cement Mortar[3]

C 186 Test Method for Heat of Hydration of Hydraulic Cement[3]

C 191 Test Method for Time of Setting of Hydraulic Cement by Vicat Needle[3]

C 204 Test Method for Fineness of Portland Cement by Air Permeability Apparatus[3]

C 226 Specification for Air-Entraining Additions for Use in the Manufacture of Air-Entraining Portland Cement[3]

C 265 Test Method for Calcium Sulfate in Hydrated Portland Cement Mortar[3]

C 266 Test Method for Time of Setting of Hydraulic Cement by Gillmore Needles[3]

C 451 Test Method for Early Stiffening of Portland Cement (Paste Method)[3]

C 452 Test Method for Potential Expansion of Portland Cement Mortars Exposed to Sulfate[3]

C 465 Specification for Processing Additions for Use in the Manufacture of Hydraulic Cements[3]

C 563 Test Method for Optimum SO_3 in Portland Cement[3]

3. Definitions

3.1 *portland cement*—a hydraulic cement produced by pulverizing clinker consisting essentially of hydraulic calcium silicates, usually containing one or more of the forms of calcium sulfate as an interground addition.

3.2 *air-entraining portland cement*—a hydraulic cement produced by pulverizing clinker consisting essentially of hydraulic calcium silicates, usually containing one or more of the forms of calcium sulfate as an interground addition, and with which there has been interground an air-entraining addition.

4. Ordering Information

4.1 Orders for material under this specification shall include the following:

4.1.1 This specification number and date,

4.1.2 Type or types allowable. If no type is specified, Type I shall be supplied,

4.1.3 Any optional chemical requirements from Table 2, if desired,

4.1.4 Type of setting-time test required, Vicat or Gilmore. If not specified, the Vicat shall be used,

4.1.5 Any optional physical requirements from Table 4, if desired.

NOTE—Attention is called to the fact that cements conforming to the requirements for all types may not be carried in stock in some areas. In advance of specifying the use of other than Type I cement, it should be determined whether the proposed type of cement is or can be made available.

[1] This specification is under the jurisdiction of ASTM Committee C-1 on Cement and is the direct responsibility of Subcommittee C01.10 on Portland Cement.

Current edition approved Dec. 9, 1986. Published February 1987. Originally published as C 150 – 40 T. Last previous edition C 150 – 85a.

[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.01.

D-43

TABLE 1 Standard Chemical Requirements

Cement Type [A]	I and IA	II and IIA	III and IIIA	IV	V
Silicon dioxide (SiO_2), min, %	...	20.0	...	...	...
Aluminum oxide (Al_2O_3), max, %	...	6.0	...	...	...
Ferric oxide (Fe_2O_3), max, %	...	6.0	...	6.5	...
Magnesium oxide (MgO), max, %	6.0	6.0	6.0	6.0	6.0
Sulfur trioxide (SO_3), [B] max, %					
When (C_3A)[C] is 8 % or less	3.0	3.0	3.5	2.3	2.3
When (C_3A)[C] is more than 8 %	3.5	[D]	4.5	[D]	[D]
Loss on ignition, max, %	3.0	3.0	3.0	2.5	3.0
Insoluble residue, max, %	0.75	0.75	0.75	0.75	0.75
Tricalcium silicate (C_3S)[C] max, %	...	...	...	35[E]	...
Dicalcium silicate (C_2S)[C] min, %	...	...	...	40[E]	...
Tricalcium aluminate (C_3A)[C] max, %	...	8	15	7[E]	5[F]
Tetracalcium aluminoferrite plus twice the tricalcium aluminate[C] (C_4AF + 2(C_3A)), or solid solution (C_4AF + C_2F), as applicable, max, %	...	...	...	...	25[F]

[A] See Note.

[B] There are cases where optimum SO_3 for a particular cement is close to or in excess of the limit in this specification. When it has been demonstrated by Test Meth C 563 that the optimum SO_3 exceeds a value 0.5 % less than the specification limit, an additional amount of SO_3, is permissible provided that, when the cement with additional calcium sulfate is tested by Test Method C 265, the calcium sulfate in the hydrated mortar at 24 ± ¼ h expressed as SO_3 does not exceed 0.50 g/L. When manufacturer supplies cement under this provision, he will, upon request, supply supporting data to the purchaser.

[C] The expressing of chemical limitations by means of calculated assumed compounds does not necessarily mean that the oxides are actually or entirely present as s compounds.

When expressing compounds, C = CaO, S = SiO_2, A = Al_2O_3, F = Fe_2O_3. For example, C_3A = 3CaO·Al_2O_3.

Titanium dioxide and phosphorus pentoxide (TiO_2 and P_2O_5) shall be included with the Al_2O_3 content. The value historically and traditionally used for Al_2O_3 in calcula potential compounds for specification purposes is the ammonium hydroxide group minus ferric oxide (R_2O_3 – Fe_2O_3) as obtained by classical wet chemical methods. T procedure includes as Al_2O_3 the TiO_2, P_2O_5 and other trace oxides which precipitate with the ammonium hydroxide group in the classical wet chemical methods. M modern instrumental methods of cement analysis determine aluminum or aluminum oxide directly without the minor and trace oxides included by the classical meth Consequently, for consistency and to provide comparability with historic data and among various analytical methods, when calculating potential compounds specification purposes, those using methods which determine Al or Al_2O_3 directly should add to the determined Al_2O_3 weight quantities of P_2O_5, TiO_2 and any other o except Fe_2O_3 which would precipitate with the ammonium hydroxide group when analyzed by the classical method and which is present in an amount of 0.05 weight % greater. The weight percent of minor or trace oxides to be added to Al_2O_3 by those using direct methods may be obtained by actual analysis of those oxides in the sam being tested or estimated from historical data on those oxides on cements from the same source, provided that the estimated values are identified as such.

When the ratio of percentages of aluminum oxide to ferric oxide is 0.64 or more, the percentages of tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite shall be calculated from the chemical analysis as follows:

Tricalcium silicate = (4.071 × % CaO) – (7.600 × % SiO_2) – (6.718 × % Al_2O_3) – (1.430 × % Fe_2O_3) – (2.852 × % SO_3)

Dicalcium silicate = (2.867 × % SiO_2) – (0.7544 × % C_3S)

Tricalcium aluminate = (2.650 × % Al_2O_3) – (1.692 × % Fe_2O_3)

Tetracalcium aluminoferrite = 3.043 × % Fe_2O_3

When the alumina-ferric oxide ratio is less than 0.64, a calcium aluminoferrite solid solution (expressed as ss(C_4AF + C_2F)) is formed. Contents of this solid solution of tricalcium silicate shall be calculated by the following formulas:

ss(C_4AF + C_2F) = (2.100 × % Al_2O_3) + (1.702 × % Fe_2O_3)

Tricalcium silicate = (4.071 × % CaO) – (7.600 × % SiO_2) – (4.479 × % Al_2O_3) – (2.859 × % Fe_2O_3) – (2.852 × % SO_3).

No tricalcium aluminate will be present in cements of this composition. Dicalcium silicate shall be calculated as previously shown.

In the calculation of all compounds the oxides determined to the nearest 0.1 % shall be used.

All values calculated as described in this note shall be reported to the nearest 1 %.

[D] Not applicable.

[E] Does not apply when the heat of hydration limit in Table 4 is specified.

[F] Does not apply when the sulfate expansion limit in Table 4 is specified.

5. Additions

5.1 The cement covered by this specification shall contain no addition except as follows:

5.1.1 Water or calcium sulfate, or both, may be added in amounts such that the limits shown in Table 1 for sulfur trioxide and loss-on-ignition shall not be exceeded.

5.1.2 At the option of the manufacturer, processing additions may be used in the manufacture of the cement, provided such materials in the amounts used have been shown to meet the requirements of Specification C 465.

5.1.3 Air-entraining portland cement shall contain an interground addition conforming to the requirements of Specification C 226.

6. Chemical Composition

6.1 Portland cement of each of the eight types shown in Section 1 shall conform to the respective standard chemical requirements prescribed in Table 1. In addition, optional chemical requirements are shown in Table 2.

7. Physical Properties

7.1 Portland cement of each of the eight types shown Section 1 shall conform to the respective standard physi requirements prescribed in Table 3. In addition, optio physical requirements are shown in Table 4.

8. Sampling

8.1 When the purchaser desires that the cement sampled and tested to verify compliance with this specifi tion, sampling and testing should be performed in acc dance with Methods C 183.

8.2 Methods C 183 are not designed for manufactur quality control and are not required for manufactur certification.

9. Test Methods

9.1 Determine the applicable properties enumerated this specification in accordance with the following metho

9.1.1 *Air Content of Mortar*—Test Method C 185.

9.1.2 *Chemical Analysis*—Methods C 114.

TABLE 2 Optional Chemical Requirements[A]

Cement Type	I and IA	II and IIA	III and IIIA	IV	V	Remarks
Tricalcium aluminate (C_3A),[B] max, %	...	...	8	...	...	for moderate sulfate resistance
Tricalcium aluminate (C_3A),[B] max, %	...	...	5	...	...	for high sulfate resistance
Sum of tricalcium silicate and tricalcium aluminate,[B] max, %	...	58[C]	...	...	...	for moderate heat of hydration
Alkalies ($Na_2O + 0.658K_2O$), max, %	0.60[D]	0.60[D]	0.60[D]	0.60[D]	0.60[D]	low-alkali cement

[A] These optional requirements apply only if specifically requested. Availability should be verified. See note in Section 4.

[B] The expressing of chemical limitations by means of calculated assumed compounds does not necessarily mean that the oxides are actually or entirely present as such compounds.

When expressing compounds, C = CaO, S = SiO_2, A = Al_2O_3, F = Fe_2O_3. For example, $C_3A = 3CaO \cdot Al_2O_3$.

Titanium dioxide and phosphorus pentoxide (TiO_2 and P_2O_5) shall be included with the Al_2O_3 content. The value historically and traditionally used for Al_2O_3 in calculating potential compounds for specification purposes is the ammonium hydroxide group minus ferric oxide ($R_2O_3 - Fe_2O_3$) as obtained by classical wet chemical methods. This procedure includes as Al_2O_3 the TiO_2, P_2O_5 and other trace oxides which precipitate with the ammonium hydroxide group in the classical wet chemical methods. Many modern instrumental methods of cement analysis determine aluminum or aluminum oxide directly without the minor and trace oxides included by the classical method. Consequently, for consistency and to provide comparability with historic data and among various analytical methods, when calculating potential compounds for specification purposes, those using methods which determine Al or Al_2O_3 directly should add to the determined Al_2O_3 weight quantities of P_2O_5, TiO_2 and any other oxide except Fe_2O_3 which would precipitate with the ammonium hydroxide group when analyzed by the classical method and which is present in an amount of 0.05 weight % or greater. The weight percent of minor or trace oxides to be added to Al_2O_3 by those using direct methods may be obtained by actual analysis of those oxides in the sample being tested or estimated from historical data on those oxides on cements from the same source, provided that the estimated values are identified as such.

When the ratio of percentages of aluminum oxide to ferric oxide is 0.64 or more, the percentages of tricalcium silicate, dicalcium silicate, tricalcium aluminate and tetracalcium aluminoferrite shall be calculated from the chemical analysis as follows:

Tricalcium silicate = $(4.071 \times \%\ CaO) - (7.600 \times \%\ SiO_2) - (6.718 \times \%\ Al_2O_3) - (1.430 \times \%\ Fe_2O_3) - (2.852 \times \%\ SO_3)$

Dicalcium silicate = $(2.867 \times \%\ SiO_2) - (0.7544 \times \%\ C_3S)$

Tricalcium aluminate = $(2.650 \times \%\ Al_2O_3) - (1.692 \times \%\ Fe_2O_3)$

Tetracalcium aluminoferrite = $3.043 \times \%\ Fe_2O_3$

When the alumina-ferric oxide ratio is less than 0.64, a calcium aluminoferrite solid solution (expressed as ss ($C_4AF + C_2F$)) is formed. Contents of this solid solution and of tricalcium silicate shall be calculated by the following formulas:

ss($C_4AF + C_2F$) = $(2.100 \times \%\ Al_2O_3) + (1.702 \times \%\ Fe_2O_3)$

Tricalcium silicate = $(4.071 \times \%\ CaO) - (7.600 \times \%\ SiO_2) - (4.479 \times \%\ Al_2O_3) - (2.859 \times \%\ Fe_2O_3) - (2.852 \times \%\ SC_3)$.

No tricalcium aluminate will be present in cements of this composition. Dicalcium silicate shall be calculated as previously shown.

In the calculation of all compounds the oxides determined to the nearest 0.1 % shall be used.

All values calculated as described in this note shall be reported to the nearest 1 %.

[C] The optional limit for heat of hydration in Table 4 shall not be requested when this optional limit is requested.

[D] This limit may be specified when the cement is to be used in concrete with aggregates that may be deleteriously reactive. Reference should be made to Specification C 33 for suitable criteria of deleterious reactivity.

9.1.3 *Strength*—Test Method C 109.

9.1.4 *False Set*—Test Method C 451.

9.1.5 *Fineness by Air Permeability*—Method C 204.

9.1.6 *Fineness by Turbidimeter*—Test Method C 115.

9.1.7 *Heat of Hydration*—Test Method C 186.

9.1.8 *Autoclave Expansion*—Test Method C 151.

9.1.9 *Time of Setting by Gillmore Needles*—Test Method C 266.

9.1.10 *Time of Setting by Vicat Needles*—Test Method C 191.

9.1.11 *Sulfate Expansion*—Test Method C 452.

9.1.12 *Calcium Sulfate in Mortar*—Test Method C 265.

9.1.13 *Optimum SO_3*—Test Method C 563.

10. Inspection

10.1 Inspection of the material shall be made as agreed upon by the purchaser and the seller as part of the purchase contract.

11. Rejection

11.1 The cement may be rejected if it fails to meet any of the requirements of this specification.

11.2 Cement remaining in bulk storage at the mill, prior to shipment, for more than 6 months, or cement in bags in local storage in the hands of a vendor for more than 3 months, after completion of tests, may be retested before use and may be rejected if it fails to conform to any of the requirements of this specification.

11.3 Packages shall identify the weight as net weight. Packages more than 2 % below the weight marked thereon may be rejected; and if the average weight of packages in any shipment, as shown by weighing 50 packages taken at random, is less than that marked on the packages, the entire shipment may be rejected.

12. Manufacturer's Statement

12.1 At the request of the purchaser, the manufacturer shall state in writing the nature, amount, and identity of the air-entraining agent used, and of any processing addition that may have been used, and also, if requested, shall supply test data showing compliance of such air-entraining addition with the provisions of Specification C 226, and of any such processing addition with Specification C 465.

13. Packaging and Package Marking

13.1 When the cement is delivered in packages, the words "Portland Cement," the type of cement, the name and brand of the manufacturer, and the weight of the cement contained therein shall be plainly marked on each package. When the cement is an air-entraining type, the words "air-entraining" shall be plainly marked on each package. Similar information shall be provided in the shipping documents accompanying the shipment of packaged or bulk cement. All pack

TABLE 3 Standard Physical Requirements

Cement Type[A]	I	IA	II	IIA	III	IIIA	IV	V
Air content of mortar,[B] volume %:								
max	12	22	12	22	12	22	12	12
min	...	16	...	16	...	16	...	...
Fineness,[C] specific surface, m^2/kg (alternative methods):								
Turbidimeter test, min	160	160	160	160	...	...	160	160
Air permeability test, min	280	280	280	280	...	...	280	280
Autoclave expansion, max, %	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Strength, not less than the values shown for the ages indicated below:[D]								
Compressive strength, psi (MPa):								
1 day	...	...	...	...	1800 (12.4)	1450 (10.0)	...	...
3 days	1800 (12.4)	1450 (10.0)	1500 (10.3) 1000[F] (6.9)[F]	1200 (8.3) 800[F] (5.5)[F]	3500 (24.1)	2800 (19.3)	...	1200 (8.3)
7 days	2800 (19.3)	2250 (15.5)	2500 (17.2) 1700[F] (11.7)[F]	2000 (13.8) 1350[F] (9.3)[F]	...	...	1000 (6.9)	2200 (15.2)
28 days	...	...	...	...	...	...	2500 (17.2)	3000 (20.7)
Time of setting (alternative methods):[E]								
Gillmore test:								
Initial set, min, not less than	60	60	60	60	60	60	60	60
Final set, min, not more than	600	600	600	600	600	600	600	600
Vicat test:[G]								
Time of setting, min, not less than	45	45	45	45	45	45	45	45
Time of setting, min, not more than	375	375	375	375	375	375	375	375

[A] See Note.
[B] Compliance with the requirements of this specification does not necessarily ensure that the desired air content will be obtained in concrete.
[C] Either of the two alternative fineness methods may be used at the option of the testing laboratory. However, when the sample fails to meet the requirements of the air-permeability test, the turbidimeter test shall be used, and the requirements in this table for the turbidimetric method shall govern.
[D] The strength at any specified test age shall be not less than that attained at any previous specified test age.
[E] The purchaser should specify the type of setting-time test required. In case he does not so specify, the requirements of the Vicat test only shall govern.
[F] When the optional heat of hydration or the chemical limit on the sum of the tricalcium silicate and tricalcium aluminate is specified.
[G] The time of setting is that described as initial setting time in Test Method C 191.

TABLE 4 Optional Physical Requirements[A]

Cement Type	I	IA	II	IIA	III	IIIA	IV	V
False set, final penetration, min, %	50	50	50	50	50	50	50	50
Heat of hydration:								
7 days, max, cal/g (kJ/kg)	...	...	70 (290)[B]	70 (290)[B]	...	...	60[C] (250)	...
28 days, max, cal/g (kJ/kg)	...	...	...	...	...	...	70[C] (290)	...
Strength, not less than the values shown:								
Compressive strength, psi (MPa)								
28 days	4000 (27.6)	3200 (22.1)	4000 (27.6) 3200[B] (22.1)[B]	3200 (22.1) 2560[B] (17.7)[B]	...	...	...	...
Sulfate expansion,[D] 14 days, max, %	...	...	...	...	...	...	...	0.040

[A] These optional requirements apply only if specifically requested. Availability should be verified. See Note in Section 4.
[B] The optional limit for the sum of the tricalcium silicate and tricalcium aluminate in Table 2 shall not be requested when this optional limit is requested. These strength requirements apply when either heat of hydration or the sum of tricalcium silicate and tricalcium aluminate requirements are requested.
[C] When the heat of hydration limit is specified, it shall be instead of the limits of C3S, C2S, and C3A listed in Table 1.
[D] When the sulfate expansion is specified, it shall be instead of the limits of C_3A and $C_4AF + 2\ C_3A$ listed in Table 1.

ages shall be in good condition at the time of inspection.

14. Storage

14.1 The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment, and in a suitable weather-tight building that will protect the cement from dampness and minimize warehouse set.

15. Manufacturer's Certification

15.1 Upon request of the purchaser in the contract order, a manufacturer's report shall be furnished at the tir of shipment stating the results of tests made on samples the material taken during production or transfer and cer fying that the applicable requirements of this specificati have been met.

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